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STUDY OF REACTOR BRAYTON POWER SYSTEMS FOR NUCLEAR ELECTRIC SPACECRAFT

FOR

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AIRESEARCH MANUFACTURING COMPANY OF ARIZONA

A Division of The Garrett Corporation
Phoenix, Arizona

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AIRESEARCH MANUFACTURING COMPANY OF ARIZONA
A DIVISION OF THE GARRETT CORPORATION
PHOENIX, ARIZONA

TECHNICAL REPORT

STUDY OF REACTOR BRAYTON POWER SYSTEMS FOR NUCLEAR ELECTRIC SPACECRAFT

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Approved by: Allen Harper
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ATTACHMENTS

Appendices: Thermacore Heat-Pipe Data
LASL Reactor Data

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SUMMARY

The study of Brayton power systems for nuclear electric spacecraft was performed to provide a basis for comparison between this system and others that have been under study for some time. Most significantly, this initial study has yielded performance parameters for the Brayton system that are very competitive with the alternative systems and envelope dimensions that are compatible with the Space Shuttle payload bay.

The primary performance parameters of system mass and radiator area were determined for systems from 100 to 1000 kW_e. Mathematical models of all system components were used to determine masses and volumes. Two completely independent systems provide propulsion power so that no single-point failure can jeopardize a mission. The waste heat radiators utilize armored heat pipes to limit meteorite puncture. The armor thickness was statistically determined to achieve the required probability of survival.

A 400-kW_e reference system received primary attention as required by the contract. The components of this system were defined and a conceptual layout was developed with encouraging results. An arrangement with redundant 400-kW_e Brayton power systems having a 1500°K (2240°F) turbine inlet temperature (TIT) was shown to be compatible with the dimensions of the Space Shuttle orbiter payload bay. The spacecraft is deployed from within the cylindrical primary radiator in a manner similar to the present Jet Propulsion Laboratory (JPL) thermionic system design. The preliminary mass determination for the complete power system is close to the desired 20 kg/kW_e for the specified Jovian environment. With further refinement, that the current Brayton conceptual design can better this goal. Study results have also shown that use of more advanced technology (higher TIT) will substantially improve system performance characteristics.

Because certain near-term missions with nuclear electric power systems are of present interest, a preliminary design concept of a 100-kW_e Brayton system was also developed. This system was designed with essentially current Brayton technology (i.e., TIT = 1325°K) for operation in the geostationary orbital environment. A flight version of this system could be available by the late 1980s.

Further studies and analyses of refined nuclear reactor Brayton space power systems are recommended for continued attention. Brayton system technology efforts should be undertaken in the near future to assure a proper base for development of flight systems in the late 1980s and 1990s.

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The excellent working relationship which has been established with JPL has contributed substantially to this study. Especially recognized are the efforts of Wayne Phillips, who was technical manager of the study, Jack Mondt, Leader of the Nuclear Thermal to Electric Power Group, and Teh Hsieh, who monitored technical aspects throughout this study. The support of James Lazar and Jerome Mullin of the NASA Office of Aeronautics and Space Technology Space Power and Propulsion Division is greatly appreciated. The continuing interest of Mr. Robert English of the NASA Lewis Research Center has been very helpful and is acknowledged with much appreciation.

In support of this study, JPL arranged for data to be provided by the Los Alamos Scientific Laboratory (Dave Buden, Dan Koenig and Ken Cooper) and by Thermacore, Inc. (Yale Eastman and Don Ernst). The extensive dialog and numerous meetings with the above named persons and others at these organizations have greatly enhanced this study.

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STUDY OF REACTOR BRAYTON POWER SYSTEMS FOR NUCLEAR ELECTRIC SPACECRAFT

1.0 INTRODUCTION

Studies are currently underway at the Jet Propulsion Laboratory (JPL) and at the Los Alamos Scientific Laboratory (LASL) to demonstrate the technical feasibility of nuclear reactor-powered spacecraft propelled by electric rocket thrusters. Such vehicles would be capable of performing detailed explorations of the solar system including rapid trips to the outer planets with massive payloads during the 1990s and into the 21st century. Particular emphasis has been placed on the definition of and on technology development for the power conversion subsystem with thermionics currently receiving primary attention.

The purpose of this study is to provide comparative information on an alternative conversion system, the Closed Brayton power system, to allow meaningful comparisons.

As a result of the large technological data base available from the development of numerous gas turbines as well as the significant R&D funding on Closed Brayton Cycle (CBC) engines over the past ten years, such engines should be considered an available technology with excellent potential for future development. Major questions to be resolved include definition of optimum operating parameters and effective integration with spacecraft elements including the launch vehicle, the nuclear subsystem (reactor and shield), the waste heat rejection system, and the space science payload. These topics are addressed in the three tasks that have been defined for this study, as described in Section 2.0. Estimation of system reliability and lifetime characteristics is of great interest, but could only be addressed

in a very preliminary way within the confines of this study. The remainder of this introduction provides additional definition of the requirements for the Nuclear Electric Spacecraft.

1.1 Study Background

Since the 1950s, the limitations of chemical rockets for extensive exploration of the solar system and other high-energy missions have been well understood. Electric-rocket propulsion was given considerable analytical and development attention during the past two decades and space flight tests were conducted. In comparison studies, nuclear electric rocket propulsion was repeatedly shown to be performance and economically effective for the more demanding missions when they would be flown.

In the early 1970s, the post-Apollo emphasis on Earth applications and, especially, the development of the Space Shuttle transportation system caused space program planners to terminate all work on nuclear systems except for radioisotope thermoelectric generators (RTGs), some advanced reactor concepts, and compatible power conversion research.

During the past several years, projections of future space mission requirements, both military and civil, have resulted in a renewed interest in advanced nuclear systems. The Department of Energy (DOE) has technology development programs in advanced nuclear energy sources for space at LASL. The NASA Office of Aeronautics and Space Technology (OAST) Space Power and Electric Propulsion Division is funding power conversion technology developments, primarily in thermionics and thermoelectrics. Although Brayton power conversion in space has a history of over 20 years, the present study represents the first effort in recent years to assess the component and system aspects in some detail using both available and obtainable technology. In particular, this study addresses the critical issue of space environment

compatible radiator design which has been recognized for some time as the major drawback to application of CBC technology.

1.2 Missions for Nuclear Electric Rocket Propelled Spacecraft

The primary missions identified by JPL for this study are solar system exploration of the outer planets with massive payloads. Figure 1 shows the net* 400-kW_e nuclear electric, rocket propelled spacecraft mass versus time of flight for various thruster exhaust velocities. Two cases are shown with different masses of shielding for the nuclear reactor. The required shielding mass is probably between these cases. Performance is also shown for a 60-kW_e solar-electric rocket-propelled spacecraft. As can be seen, substantial masses can be placed in Jupiter orbit(1)** which would represent a likely first use for the nuclear electric spacecraft. Reference 1 also contains data on flights to other outer planets and on a solar escape mission with high net mass and reasonable trip times. Further trajectory optimization of these and other high-energy missions are expected to result in a strong recommendation for the development of nuclear electric rocket propulsion capability.

In a more recent paper(2), Phillips and Pawlik discuss the design of a nuclear electric propulsion system, including the selection of thrusters and propellant for outer planet (Saturn, Uranus and Neptune) exploration. A power level between 200 and 250 kW_e is recommended with current technology for the early missions and growth potential for more difficult later missions. These missions could be accommodated without significant changes in the basic nuclear reactor heat source and heat rejection system.

*Total spacecraft mass less the following term for Cases A and B--(1.03 propulsion system mass plus shielding mass).
**Numbers in parenthesis refer to the list of references in Section 6.0.

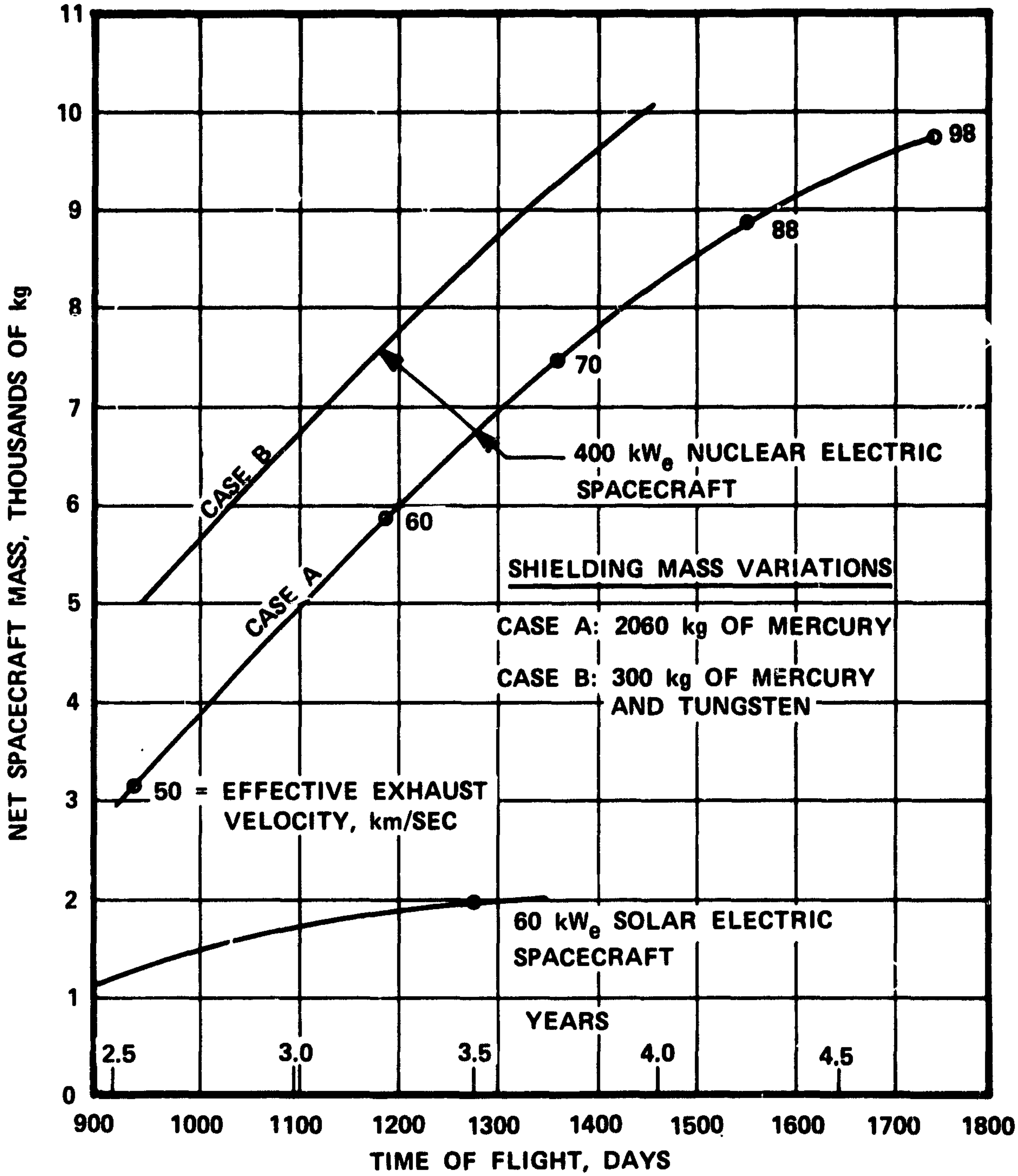

Figure 1. Net Spacecraft Mass in Jupiter Orbit Vs Time of Flight.

Other high-energy missions in the 1990s and beyond will include such candidates as orbital transfer vehicles, both in geocentric orbits and throughout cislunar space, highly maneuverable military spacecraft, and the initial versions of solar system cruisers.

1.3 Overall Study Approach

The study of CBC systems depends on the use of computer-based analytical methods. Only with such methods can thousands of candidate systems be designed and evaluated parametrically. A computer model based on appropriate guidelines and constraints has been created showing the variables intrinsic to CBC systems to be studied. The guidelines for the model are discussed in Section 1.4. The computer study method is described in Section 2.1.1.

A reference system design at 400 kW_e was evaluated in substantial detail and is discussed at some length in Section 2.1.2. Because of prospective interest in lower power systems, a preliminary layout of a 100-kW_e system was prepared and is shown in Section 2.1.3. Analytical results for systems from 100 to 1000 kW_e using near-term and obtainable Brayton technologies are given in Section 2.1.4.

The major technical challenge of this study was the identification of a credible heat-pipe radiator. Early in the study, the Brayton power conversion system design parameters were selected from computer results which did not include all system components and which included a liquid-cooled radiator. A heat-pipe radiator was then designed using a separate radiator computer program and the mass adjusted accordingly. In the latter phase of the study, these computer models were merged and analytical representations of all system components were included. Achievement of this overall design tool is a major accomplishment of this study. Throughout this investigation, layouts of radiators were made and evaluated against two constraints--reasonable mass and ability to fit into the Space Shuttle bay.

Specific heat-pipe designs were evaluated by Thermacore, Inc. under a JPL contract. The study results are discussed in Section 2.2.4 and presented in toto in Appendix A. The radiator geometry is discussed in greater detail in Section 2.3.

1.4 Study Guidelines

There were two primary goals of this study--first, to study nuclear electric propulsion (NEP) power systems from 100 to 1000 kW_e, and second, to create a reference design including a system layout at 400 kW_e. The following constraints and guidelines were given in the JPL contract (3) or were expressed as highly desirable by JPL representatives:

(a) The system should be designed for technology attainable in the 1985 to 1990 time frame.

(b) The system must produce the voltage level desired by the ion thrusters.

(c) System components must be placed within the shadow of the reactor shield.

(d) The 400-kW_e system and payload should fit within the Space Shuttle bay.

(e) These systems should be designed to operate in a recently defined Jovian micrometeoroid environment throughout the mission life.

(f) System lifetime is 120,000 hours.

(g) The system specific mass at 400 kW_e should be less than 20 kg/kW_e.

The following additional guidelines were assumed by AiResearch:

(a) No single-point failures are allowed; hence, all systems include the mass of a redundant system.

(b) The 100-kW_e system would use essentially state of the art technology.

(c) The 400- and 1000-kW_e systems can utilize longer term technology.

(d) Turbomachinery design is current state of the art.

2.0 TECHNICAL DISCUSSION

2.1 Task 1 - Power System Conceptual Design Studies

The method and the results of the study of power systems between 100 and 1000 kW_e are described in the following sections. Conceptual designs at 400 and 100 kW_e are presented in greater detail.

2.1.1 Study Method

The CBC computer design program was used to design thousands of candidate systems. This program requires input of key thermodynamic parameters to begin the cycle design. The output is complete preliminary design of the resultant systems, including masses of all components in both tabular and plotted forms. These systems are examined in detail and a reference system is selected. From the geometry of the components, a layout of the selected design can be made.

Table 1 lists the array of parameters that were studied. The most significant parameter is power level because system mass is a strong function of power level. The TIT and cycle temperature ratio* are the next most important parameters. The cycle temperature ratio dictates the cycle efficiency (from the Carnot efficiency equation) depending upon the other parameters selected. TIT coupled with the cycle temperature ratio affects radiator size. The compressor specific speed, rotor speed, and power level determine the performance level of the turbomachinery and system pressure level. Rotor speed also determines the mass of the turbomachinery. Recuperator effectiveness affects thermal input, the mass of the recuperator, and radiator size. The pressure loss parameter has a strong effect on the

*Ratio of compressor inlet temperature (CIT) to TIT.

TABLE 1

INITIAL BRAYTON POWER SYSTEM STUDY PARAMETERS

	Units	Values			
Net Output Power Level	kW_e	100	400	1000	
Turbine Inlet Temperature	°K	1150	1325	1500	1650
Cycle Temperature Ratio (CIT/TIT)		0.25 to 0.40			
Compressor Specific Speed		0.07 to 0.15			
Rotating Speed	krpm	12 to 48			
Recuperator Effectiveness		0.88 to 0.97			
Pressure Loss Parameter		0.92			

mass of the heat exchangers and system performance. The value that was selected (0.92) allows good system performance and reasonable heat exchanger mass.

Other variables that affect system mass include compressor pressure ratio, heat exchanger pressure drop, radiator sink temperature, and meteoroid flux. Compressor pressure ratio is selected to yield maximum system performance. Heat exchanger pressure drops are split between the heat exchangers for minimum system mass. Reactor thermal power affects both reactor and shield mass. The meteoroid flux can drastically affect radiator mass. All of these parameters are modeled in the computer code.

The computer program is a series of overlay programs, i.e., all of the thermodynamic cycles are defined first; then, the recuperator for each cycle is designed, next the radiator for each cycle is designed, etc. Finally, these results are matched, listed, and plotted. Figure 2 shows the manner in which information is transferred between these programs.

The first and most important step is the cycle analysis. This program uses the input parameters shown in Table 1. Some other secondary inputs, such as alternator design characteristics, are also used. This program, based on empirical performance maps of the compressor and turbine, will design a thermodynamic cycle for a given combination of the above parameters. Among the information defined is compressor and turbine efficiencies and sizes, alternator windage and size, cycle efficiency, and the thermodynamic state points. From the thermodynamic state point and rotor size, the rotating unit mass is calculated. This design point information is stored on the computer disk. The program continues to design cycles until all combinations of parameters are exhausted.

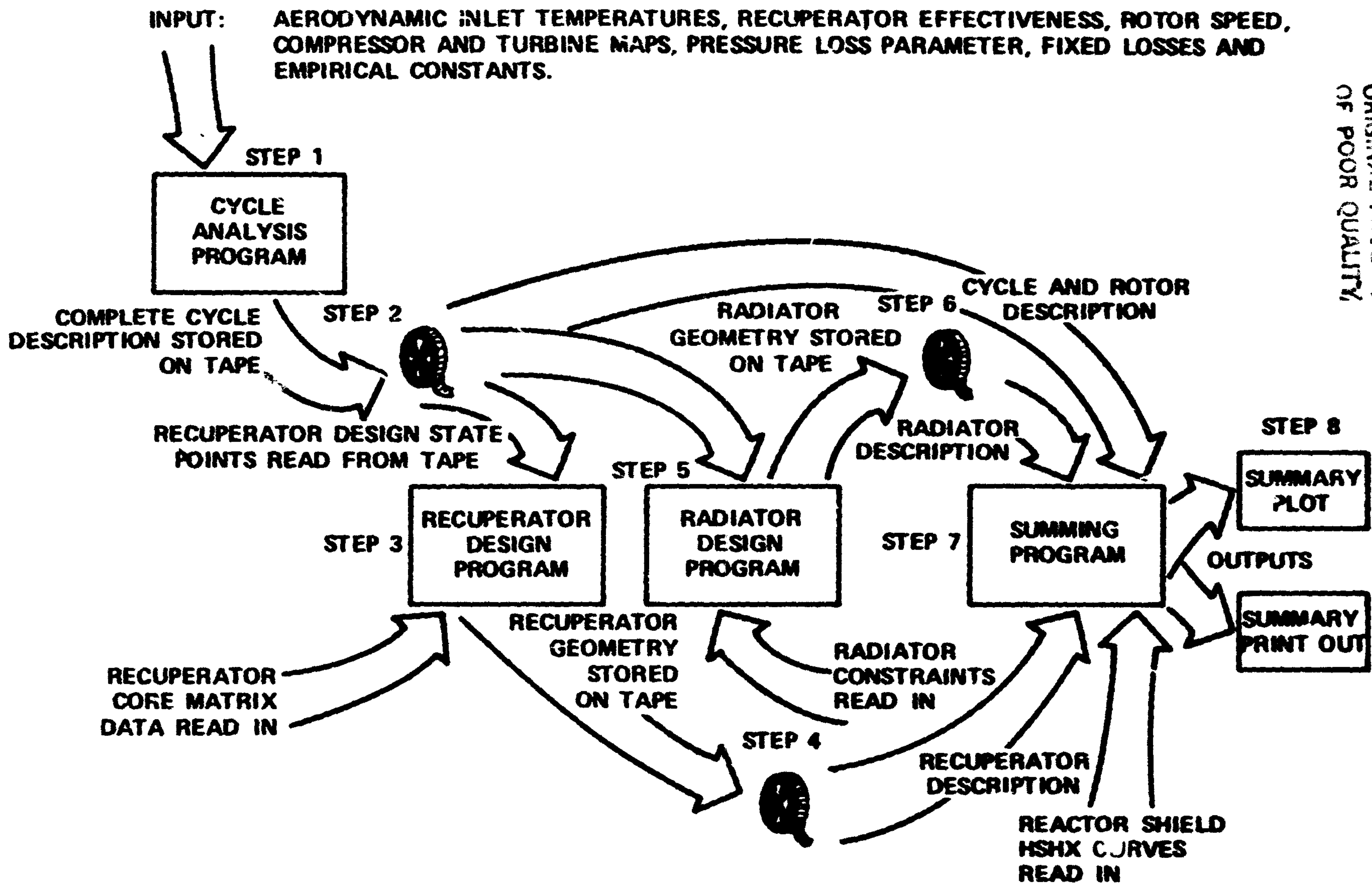

Figure 2. Brayton Space Power System Design Methodology

The next step is the design of the recuperator. The recuperator core matrix and other minor inputs are read in. Next, the cycle state point data are read from the computer disk. The recuperator is designed, and its mass and geometry are stored on the computer disk. After all of the recuperators are designed, the radiator design begins.

The heat-pipe radiator design program was added as a program option during this study. The calculation method is discussed in Section 2.3.6 (Radiator Conceptual Design). Like the recuperator program, it requires some basic input such as heat-pipe diameter, spacing, and length; gas heat exchanger data; micrometeoroid model; etc. It also uses the cycle state point data to design a heat-pipe radiator. The dimensions and mass of each radiator are stored on the computer disk. After a heat pipe radiator has been designed for each cycle, the calculation proceeds to the summing program.

In the summing program, the information stored on the computer disk is merged to form a complete system description. The mass of the remaining system components is calculated as a function of the appropriate cycle variables. Examples are duct mass, reactor mass, shield mass, and insulation mass. After the mass of every component is defined, the total system mass, system specific mass, and specific radiator area are calculated. An abbreviated cycle description is printed, and the specific mass and area are plotted. The plots are shown and discussed in Section 2.1.4. When a candidate system is selected, an option that prints the geometry and performance of all of the components is used. From this geometry, a system layout can be made.

2.1.2 Reference System Design at 400 kW_e

The 400-kW_e system is illustrated in Figure 3. This configuration uses technology expected to be available at least by 1990 and is

JOVIAN ENVIRONMENT TIT = 1500°K (2240°F)

MASS SUMMARY	kg
REACTOR	850
REACTOR SHIELD	800
HEAT SOURCE HEAT EXCHANGERS (2)	420
CRU (2)	430
ALTERNATOR RADIATOR	150
RECUPERATORS (2)	730
RADIATOR	4040
DUCTING & MISCELLANEOUS	400
POWER CONDITIONING	150
STRUCTURE	300
	8270

SPECIFIC MASS = 20.7 kg/kW_e

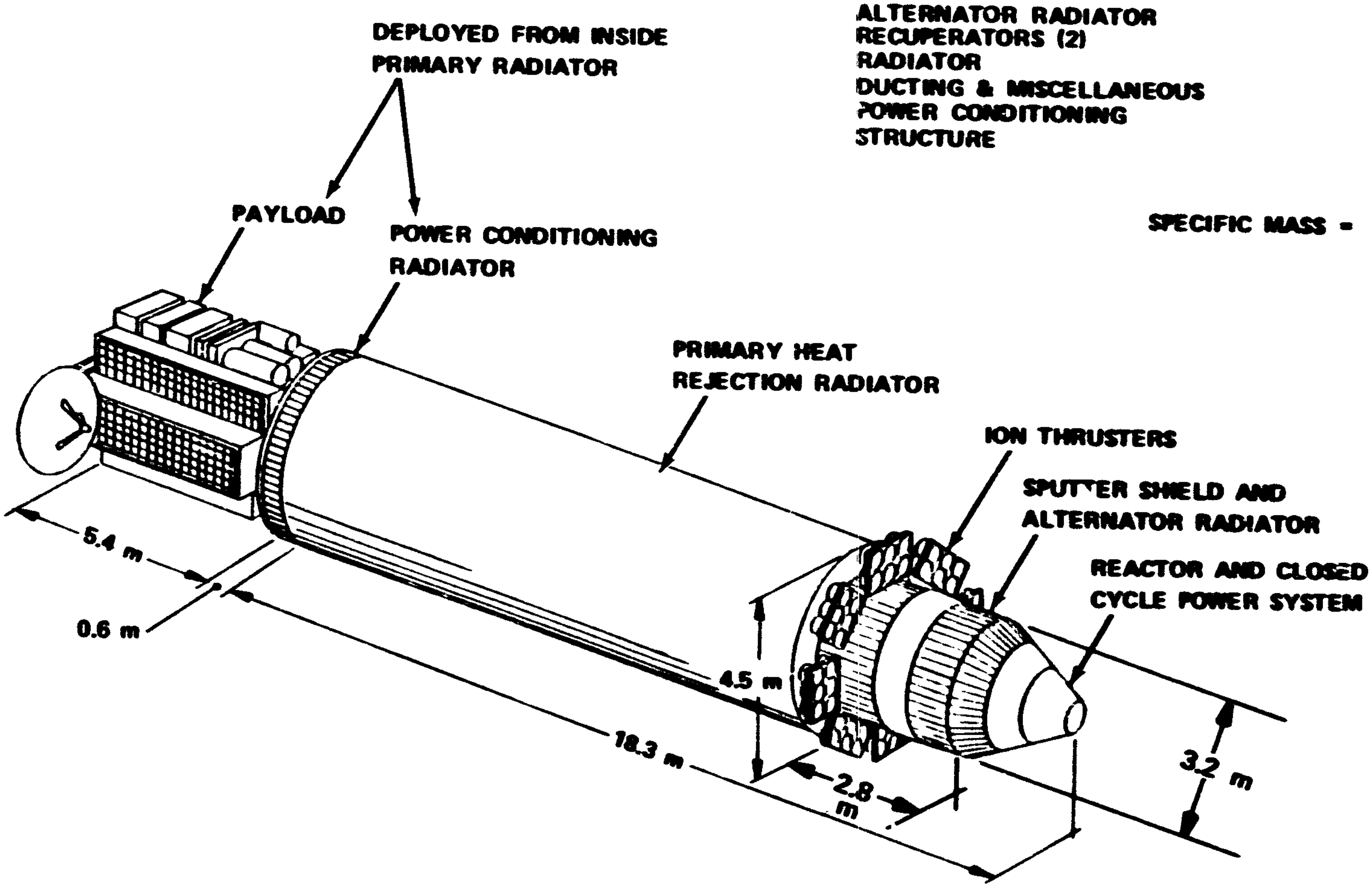

Figure 3. Nuclear Electric Spacecraft Design with a 400-kW_e Brayton Power System

designed for operation near Jupiter. The largest and most noticeable component is the primary heat rejection radiator. Because this entire system must fit into the Space Shuttle bay, the radiator length was selected with care.

The spacecraft is located forward of all other components. To fit the payload bay envelope, several components are deployed after the unit is released from the Shuttle. The spacecraft and power-conditioning radiator both telescope from inside the primary heat rejection radiator (this is also a feature of the baseline thermionic system). The ion thruster panels are rotated to a position normal to the axis of the spacecraft.

At the aft end of the spacecraft are the reactor and closed cycle power conversion systems. The reactor is the rearmost component. Inside the sputter shield and alternator radiator are the dual rotating groups, recuperators, and heat source heat exchangers. This configuration is simple and very compact.

Figure 3 shows that the specific mass is 20.7 kg/kW$_e$ With further refinement, the system specific mass could be decreased to meet or be less than the 20 kg/kW$_e$ design goal. For example, relaxation of the micrometeoroid environment to reflect the relatively low fraction of the mission duration spent close to Jupiter would result in the goal being surpassed without further refinement. More complete detail on this system is given in Section 2.3.

2.1.3 Preliminary Conceptual Design at 100 kW$_e$

The 100-kW$_e$ conceptual design was studied in a very cursory fashion near the end of the study because of indications of early mission interest in this power level. Figure 4 shows the power system applied to a large telescoping and deploying space antenna. This

NEAR EARTH ENVIRONMENT TIT = 1325°K (1925°F)

MASS SUMMARY	kg
REACTOR	350
REACTOR SHIELD	220
HEAT SOURCE HEAT EXCHANGERS (2)	120
CRU (2)	150
ALTERNATOR RADIATOR	60
RECUPERATORS (2)	350
RADIATOR	1340
STRUCTURE, DUCTING & MISCELLANEOUS	350
POWER CONDITIONING AND CONTROLS	100
	3040

SPECIFIC MASS = 30.4 kg/kW_e

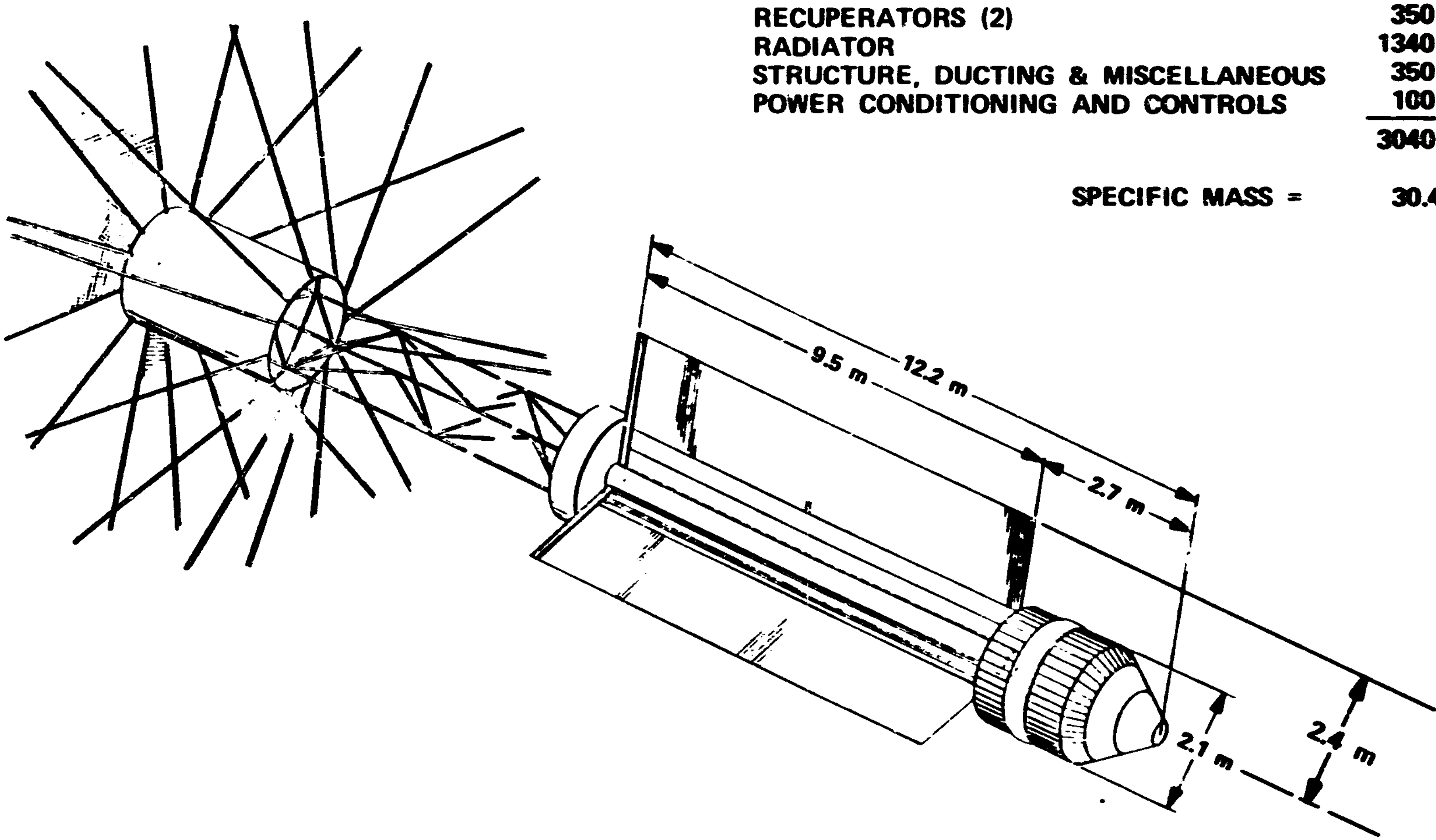

Figure 4. Preliminary 100-kW_e Nuclear Electric Spacecraft Design

power system configuration will fit easily into the Space Shuttle payload bay. The component arrangement is generally similar to the 400-kW_e system described previously. The mass summary given in Figure 4 reflects a conservative design based essentially on currently available technology. Two completely independent systems provide propulsion power so that no single-point failure can jeopardize a mission. Although the radiator is "Y" shaped, a cylindrical radiator could also be used which would be more compact but more massive.

The specific mass of 30.4 kg/kW_e could quite clearly be significantly reduced by the use of more advanced technology (higher TIT). Even at the lower TIT, appreciable reduction could be achieved with further refinement. Unfortunately, such refinement was not possible within the resources available for this study.

2.1.4 Analytical Results from 100- to 1000-kW_e Studies with Near-Term and Obtainable Brayton Technologies

Figures 5 through 12 are "shotgun" plots generated by the previously described method (Section 2.1.1). Representative plots are included for three output powers (100, 400, and 1000 kW_e). These plots are presented as representative examples of the analytical approach but do not reflect a significant improvement (use of dual diameter or necked heat pipes), which was made relatively late in the study. The effects of this improvement are described later in this section. Each point on these plots represents a specific system design according to the parameters of Table 1. Each set of results consists of separate plots of specific mass and specific radiator area. The specific mass includes the heat source, two completely redundant loops for all the power conversion components, the waste heat radiator, and required power conditioning components.

Plots of the 400-kW_e system, designed for a 1995 flight with a 1500°K (2240°F) TIT are shown in Figures 5 through 8. A five-year

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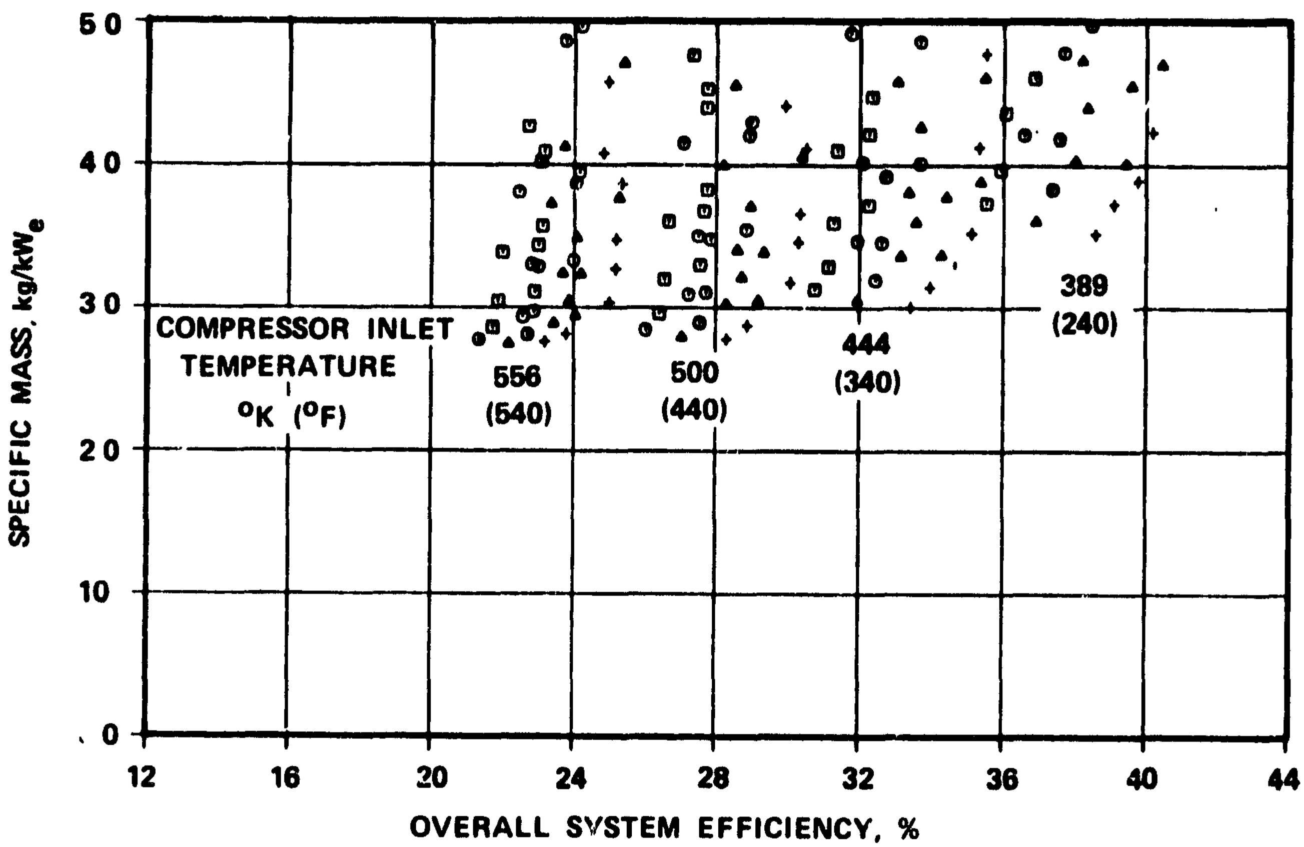

Figure 5. Specific Mass vs Overall System Efficiency of 400-kW$_e$ System at a Turbine Inlet Temperature of 1500°K (2240°F) in a Jovian Environment

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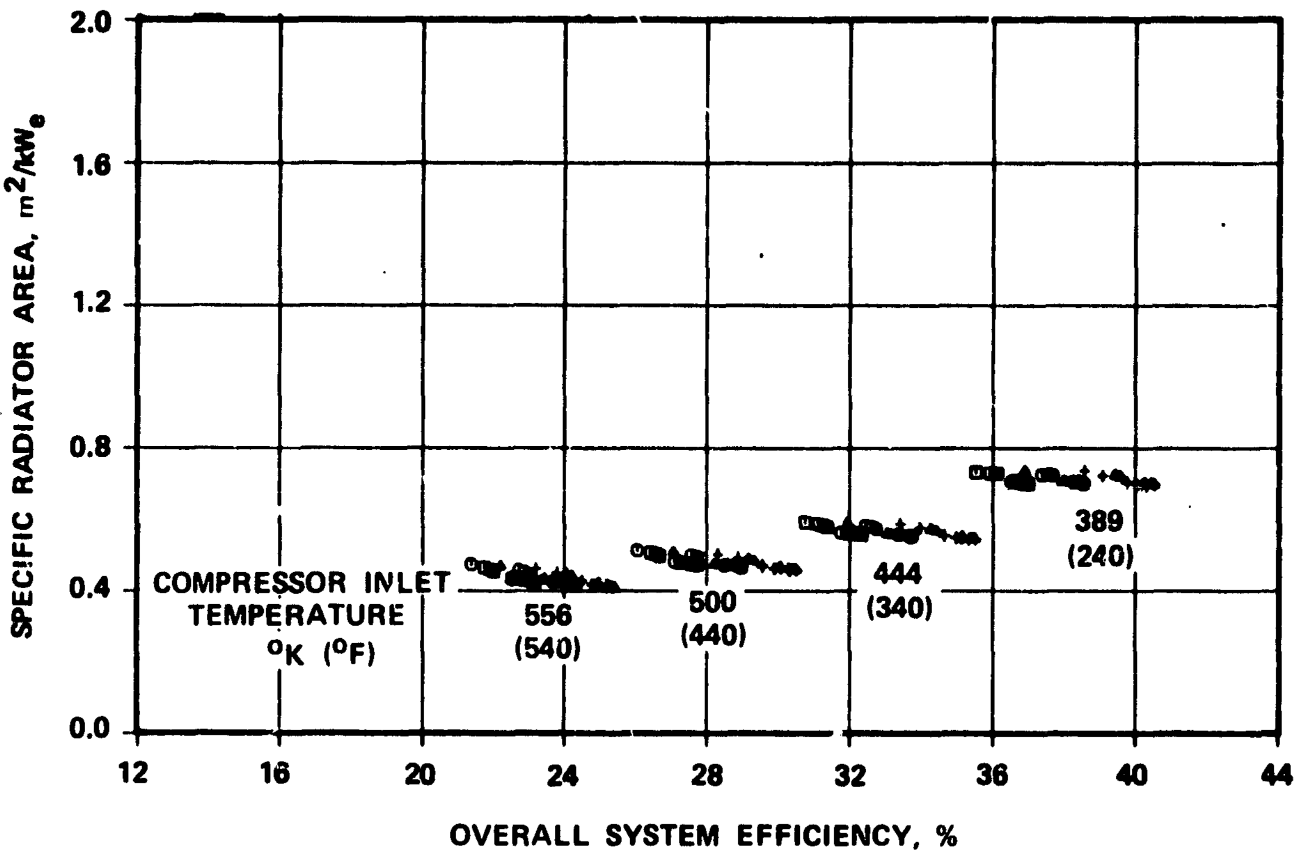

Figure 6. Specific Radiator Area vs Overall System Efficiency of 400-kW_e System at a Turbine Inlet Temperature of 1500°K (2240°F) in a Jovian Environment

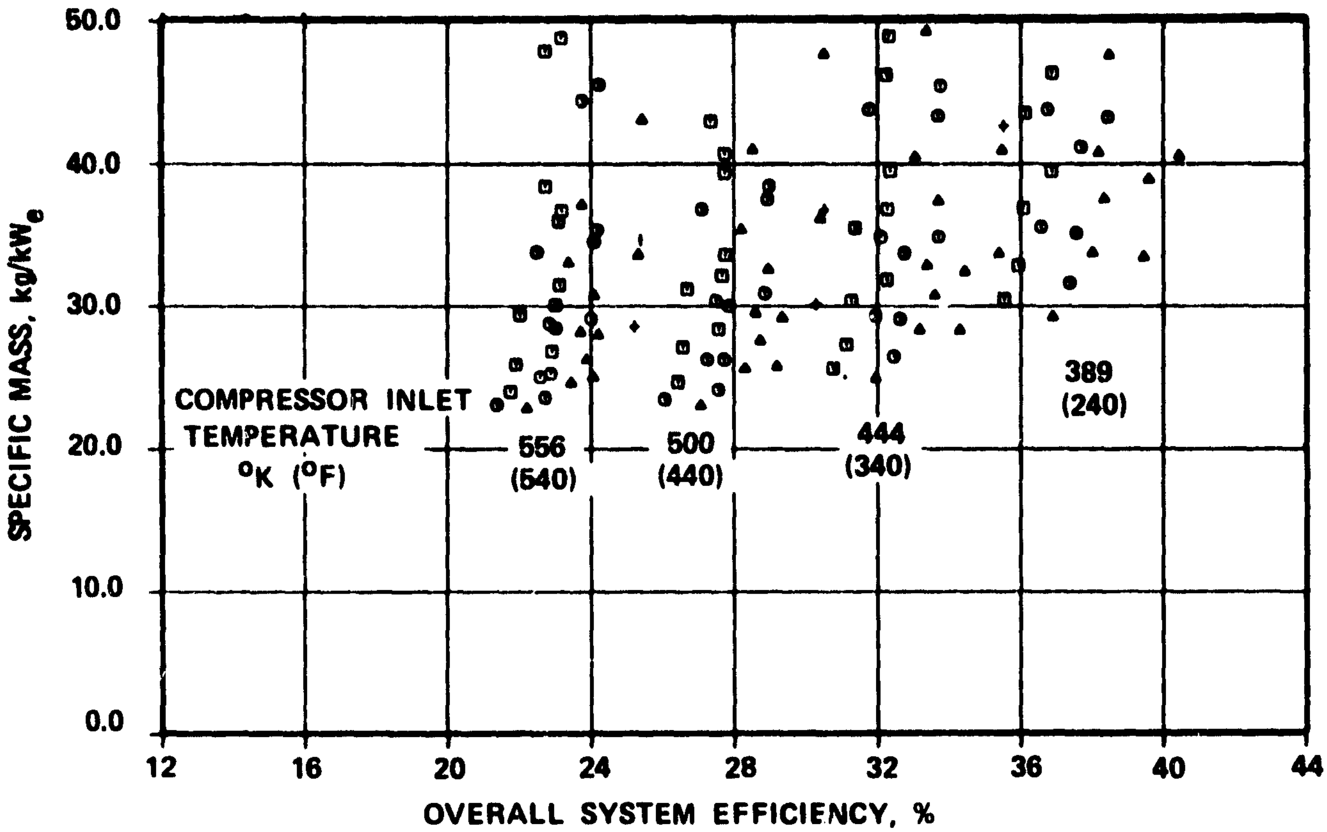

Figure 7. Specific Mass vs Overall System Efficiency of 400-kW_e System at a Turbine Inlet Temperature of 1500°K (2240°F) in a Near-Earth Environment

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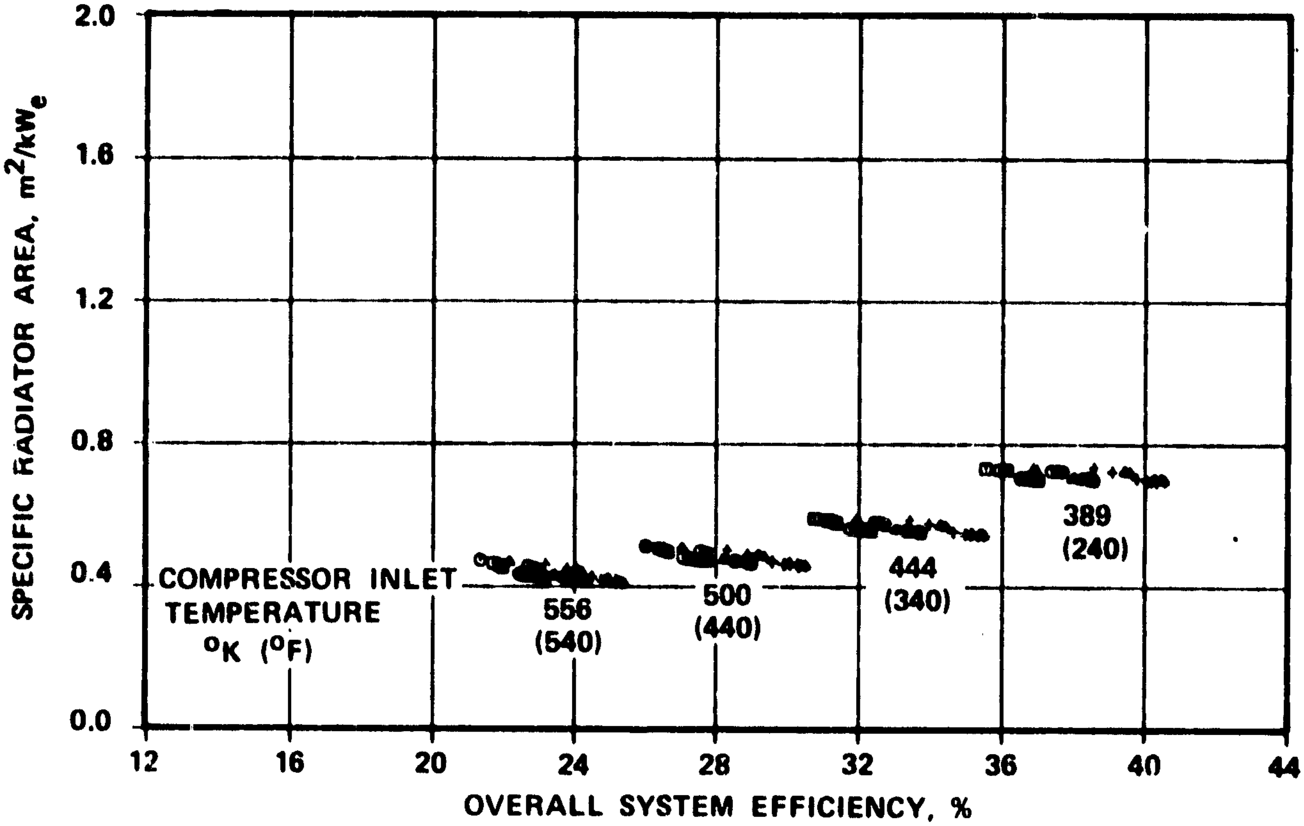

Figure 8. Specific Radiator Area vs Overall System Efficiency of 400-kW_e System at a Turbine Inlet Temperature of 1500°K (2240°F) in a Near Earth-Environment

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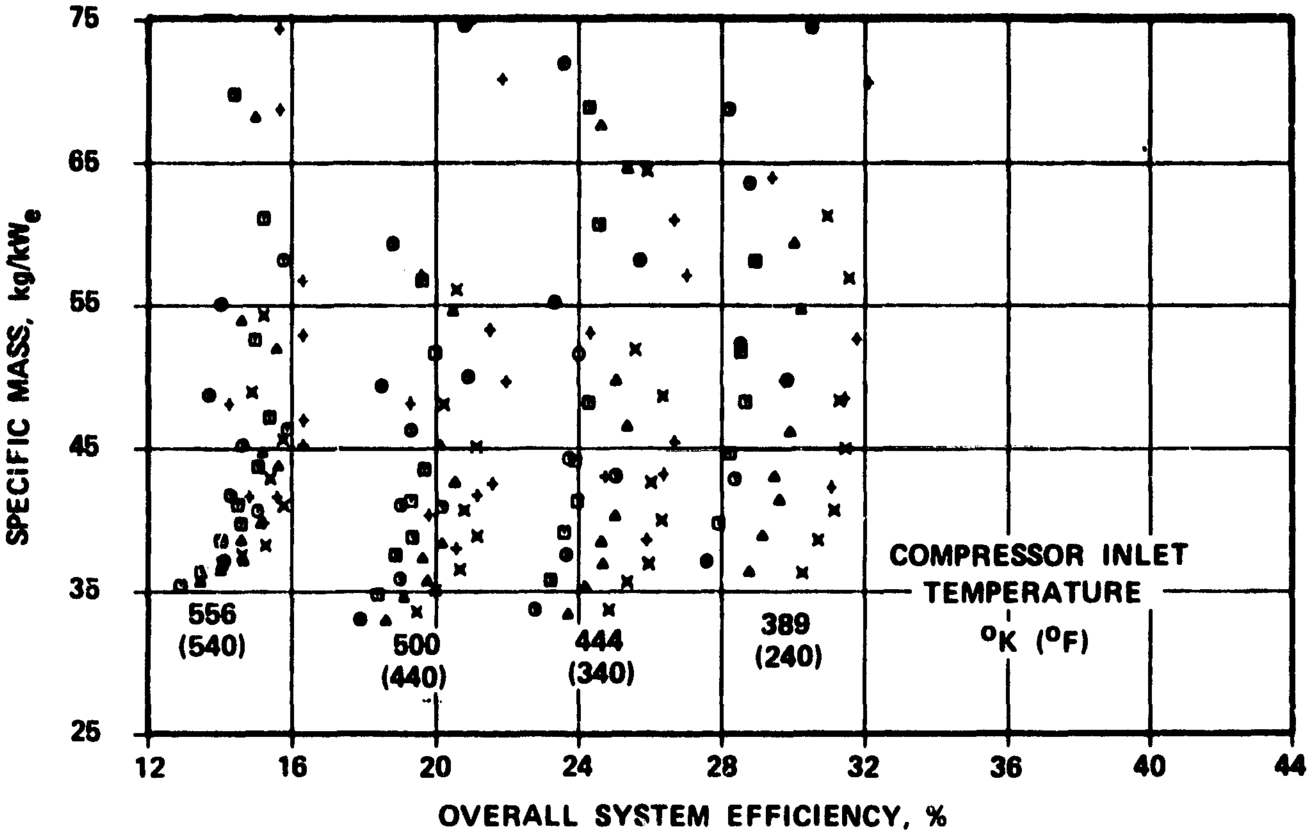

Figure 9. Specific Mass vs Overall System Efficiency of 100-kW_e System at a Turbine Inlet Temperature of 1325°K (1925°F) in a Near-Earth Environment

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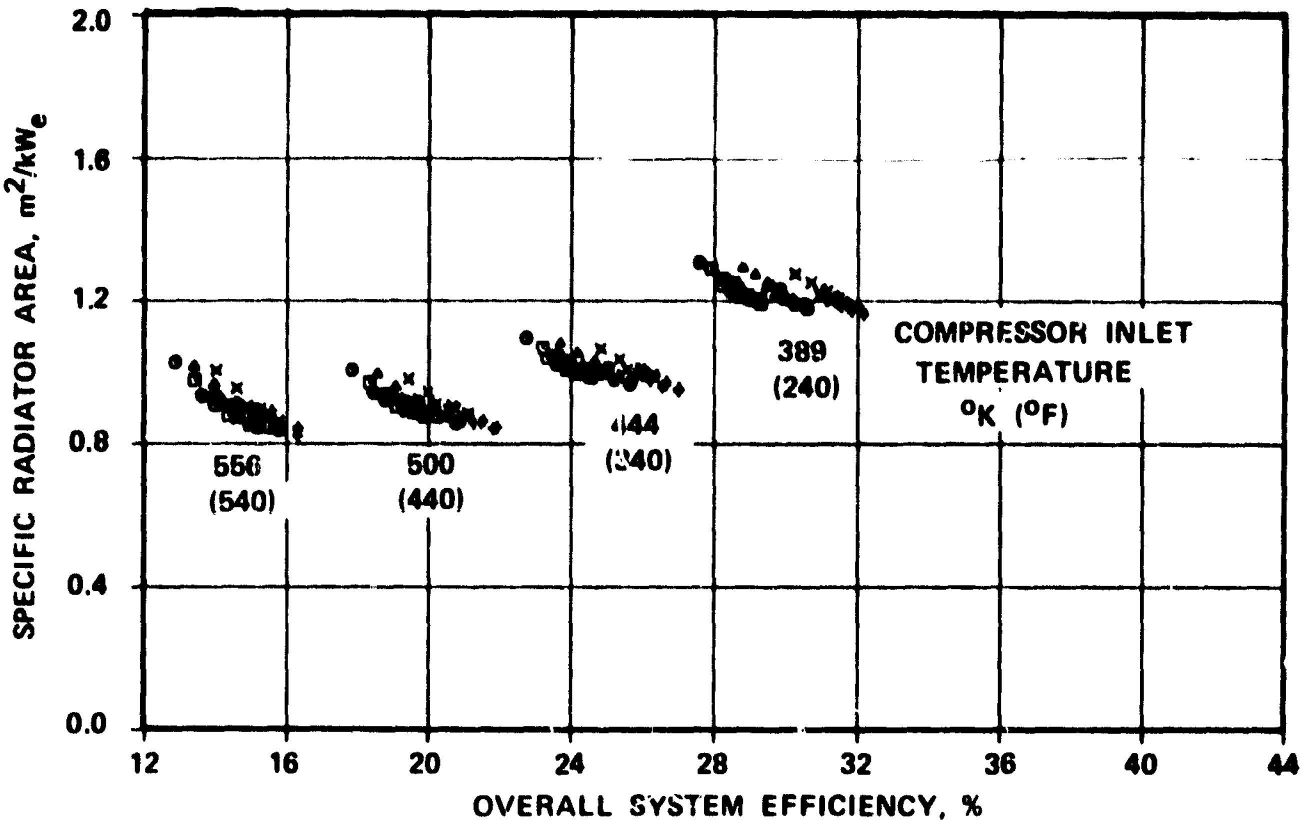


Figure 10. Specific Radiator Area vs Overall System Efficiency of 100-kW_e System at a Turbine Inlet Temperature of 1325°K (1925°F) in a Near-Earth Environment

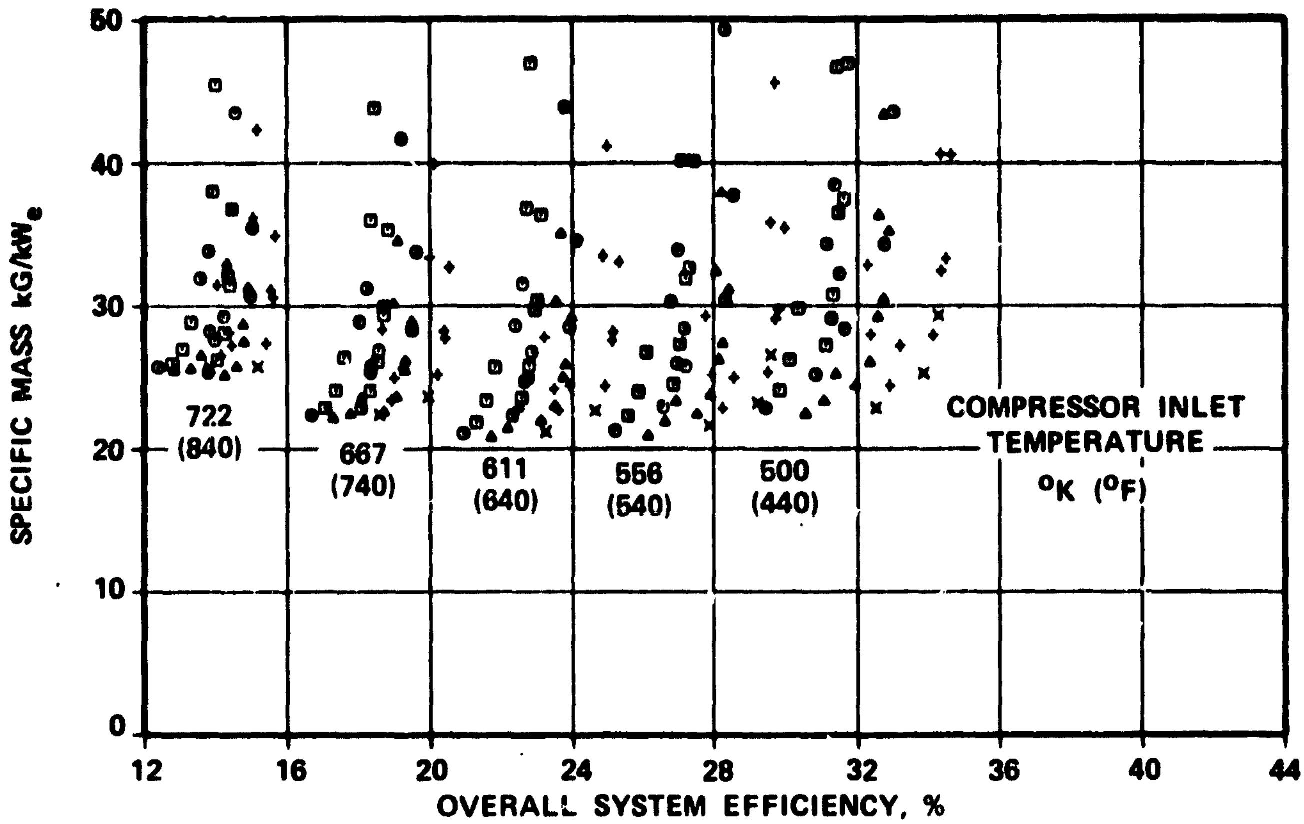


Figure 11. Specific Mass vs Overall System Efficiency of 1000-kW$_e$ System at a Turbine Inlet Temperature of 1650°K (2510°F) in a Jovian Environment

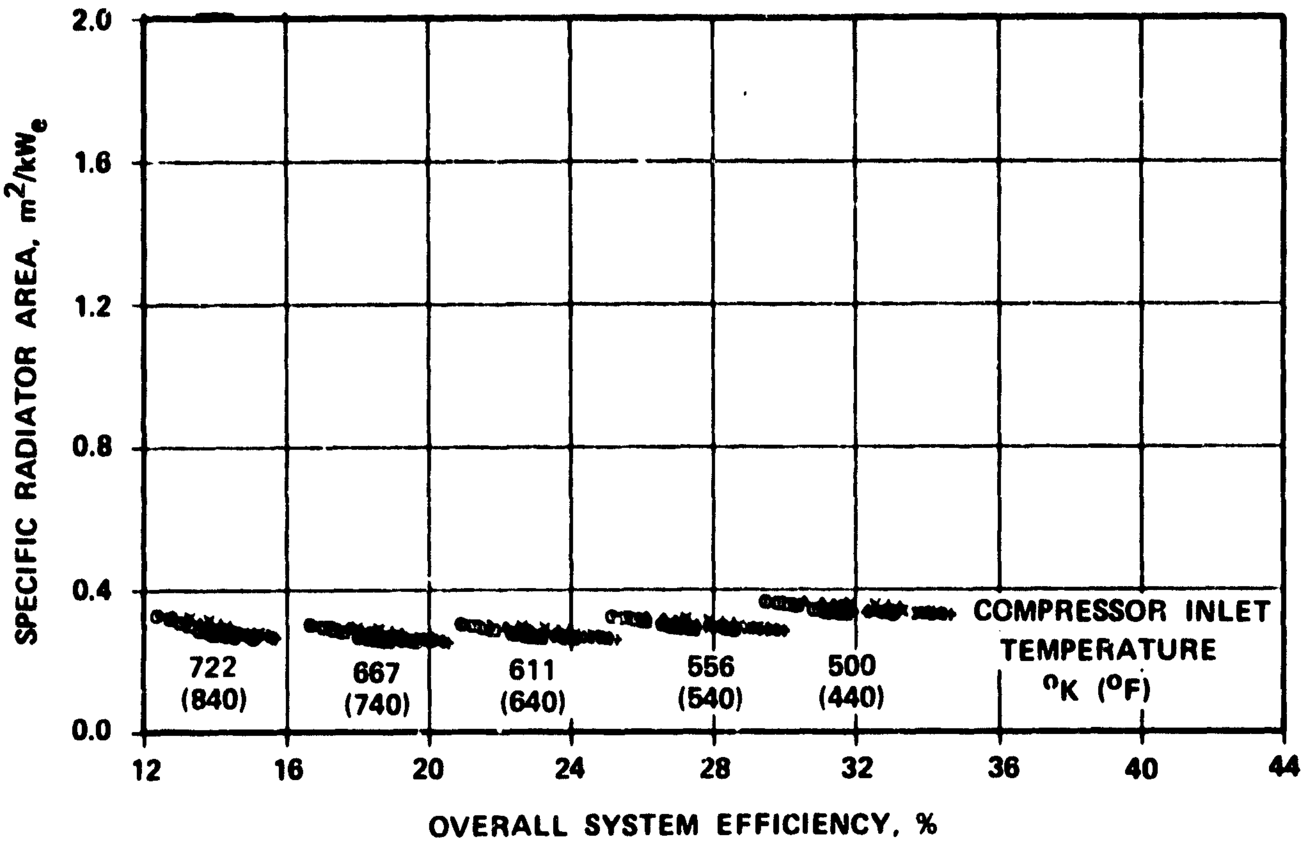


Figure 12. Specific Radiator Area vs Overall System Efficiency of 1000-kW_e System at a Turbine Inlet Temperature of 1650°K (2510°F) in a Jovian Environment

flight system development is assumed with the result that this TIT, which can be attained with high-strength refractory materials, should be state-of-the-art by 1990. The inferences of this technology development schedule are discussed subsequently. The waste heat radiators for these systems employ the fixed cylindrical geometry shown in Figure 3. Previously, a hinged, three-panel design had been considered that was somewhat less massive but required in-space assembly operations (automated welding or brazing at the 400-kW_e power level. Comparison of the specific mass data for the Jovian (Figure 5) and near-Earth (Figure 7) environments shows the substantial effect of the meteoroid armor requirement. These systems have masses that are well within the capability of a single Shuttle launch and dimensions that fit within the payload bay.

Figures 9 and 10 show the specific mass and specific radiator area for 100-kW_e systems designed for the near-Earth micrometeoroid environment and for a TIT of 1325°K (1925°F). These systems would be based on essentially existing technology (mostly superalloy with some well-characterized refractory hot section components) which results in relatively large masses and radiator areas. The system configuration with a three-panel radiator is shown previously in Figure 4 and fits easily within the Shuttle payload envelope.

The specific mass and radiator areas characteristic for 1000-kW_e systems are shown in Figures 11 and 12. The TIT for these systems, 1650°K (2510°F), is commensurate with ceramic technology which should be available by 1995 (yielding a projected operational date of 2000). Specific mass and radiator area are the lowest of all the systems analyzed, illustrating most significantly the payoff of advanced technology. As a result of a number of on-going programs (four to six), AiResearch concludes that the ceramic technology will be available as outlined above. Indeed, these time frame projections may be conservative rather than optimistic.

Table 2 shows the effect of environment, power level, and turbine inlet temperature on specific mass and radiator area. The table lists the specific radiator area of the system that has minimum specific mass. The table shows that both specific mass and radiator area decrease as power level and/or turbine inlet temperature increase. The requirement to operate in the Jovian environment has an adverse effect on system mass.

In Table 2, the values in the column labeled "Specific System Mass" were determined directly from the "shotgun" plots. As noted previously, the radiator is by far the most massive component in the power system. As described in Section 2.2.5, a modification to use "dual-diameter" heat pipes was defined late in the study. In this approach, a large diameter is used in the evaporator section to yield adequate heat transfer from the cycle working fluid and a smaller diameter is used for the condenser. This modification allowed the radiator to be redesigned for a much lower mass. Estimates were made of the reductions possible, and the resultant modifications to the specific mass are listed in the column labled "Specific System Mass with Refined Radiator". The plots may still be used to determine the relative merits of alternative system design points.

The most important parameter in Table 2 is the specific mass of the 400-kW_e system. For the Jovian environment, the specific mass is 21 kg/kW_e which is within 5 percent of the design goal. With further refinement, this value could probably be made less massive than the goal. 400 kW_e systems designed for the near-Earth environment are lighter than the design goal of 20 kg/kW_e. The advanced 1000-kW_e system for Jovian environment has the highest performance of all with a specific mass of 15 kg/kW_e.

TABLE 2

SUMMARY OF SELECTED BRAYTON SYSTEM DESIGNS

Power Level kW_e	Turbine Inlet Temperature °K	Environment	Specific System Mass kg/kW_e	Specific System Mass With Refined Radiator kg/kW_e	Specific Radiator Area m^2/kW_e
400	1500	Jovian	28	21	0.42
400	1500	Near-Earth	23	19	0.42
100	1325	Jovian	46	41	1.0
100	1325	Near-Earth	34	30	1.0
100	1500	Near-Earth	29	26	0.72
1000	1500	Jovian	26	20	0.38
1000	1650	Jovian	21	17	0.30
1000	1800	Jovian	18	15	0.25

2.2 Task 2 - Primary Radiator Conceptual Design

In this task, primary waste heat radiator layout studies were undertaken. An analytical model of the radiator was defined and used in Task 1 to create the designs. Finally, the radiator design was checked against the Thermacore heat-pipe data. The geometry of the radiator selected for the 400-kW_e system is discussed in Section 2.3.5 below.

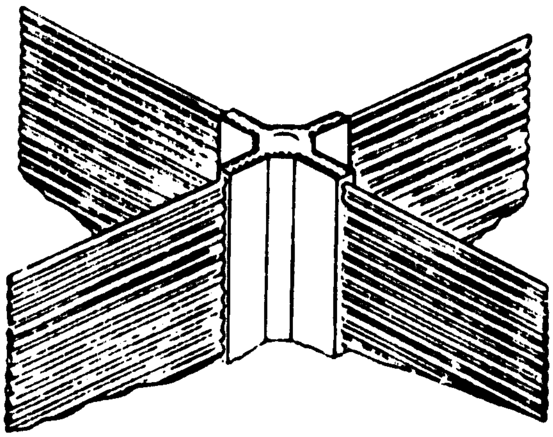
2.2.1 Configuration Studies

The radiator configurations derived during the layout study are shown in Figure 13. There are four designs labeled (A) through (D).

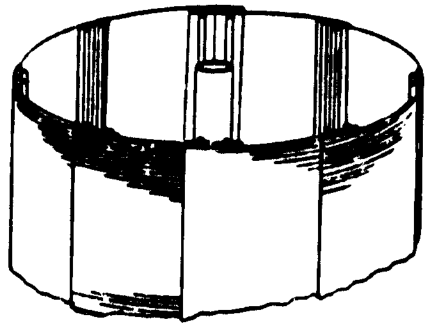
All of these configurations are similar in their design approach. Each has a gas-to-heat-pipe heat exchanger where the heat is transferred to the evaporator section of the heat pipe. Each has a condensing section and fin from which the waste heat is radiated. Each has armor protection for the condenser section. Some radiate from only one side of the panel.

Configuration (A) is based on a LASL design approach. It has four heat-pipe panels with a cruciform gas to heat pipe heat exchanger. Inside the heat exchanger are small diameter tubes which are joined to the evaporator. These tubes carry the working fluid and provide additional heat transfer surface.

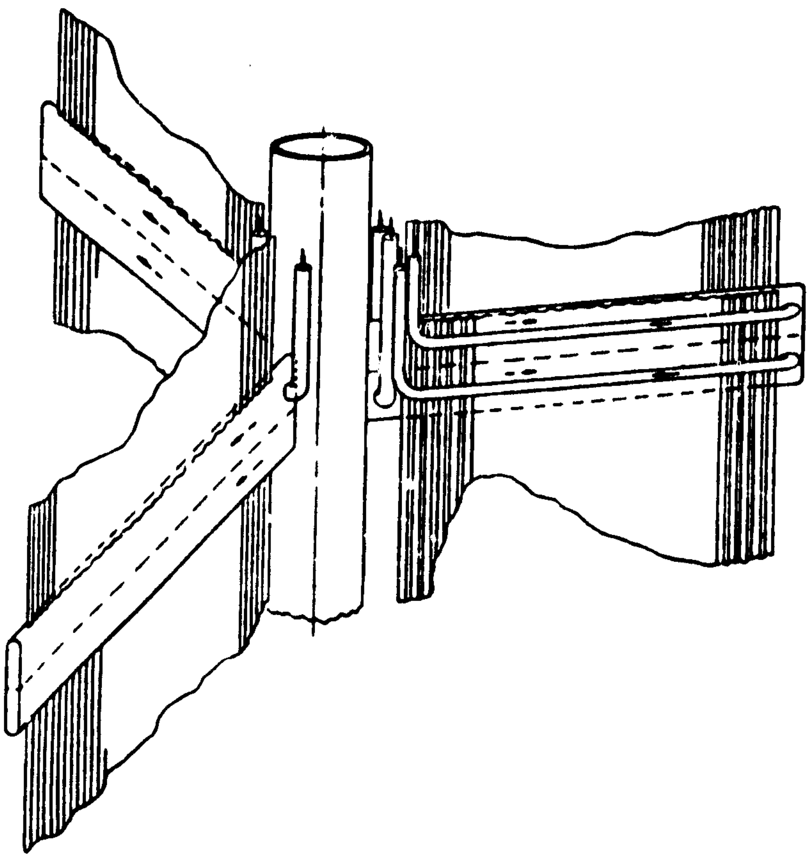
Configuration (B) has eight slightly curved panels which together make a right circular cylinder. Each panel has two gas-to-heat-pipe heat exchangers because these are two power conversion systems. Each gas heat exchanger is protected from meteoroid impact by the adjacent heat-pipe panels that overlap the heat exchangers.



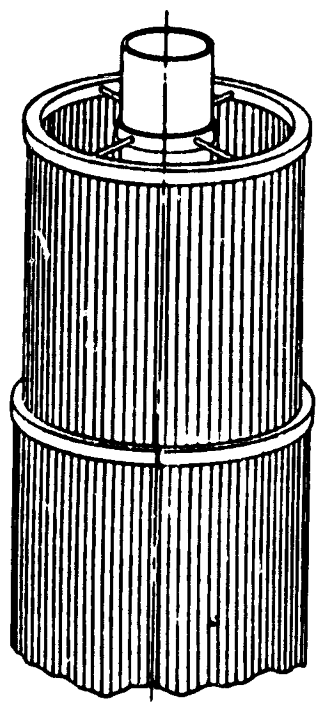
A. FOUR PANEL (LASL) DESIGN



B. CYLINDRICAL DESIGN



C. THREE PANEL DESIGN



D. CAMPING-CUP DESIGN

Figure 13. Conceptual Primary Radiator Designs

Configuration (C) is a three-panel design with axial heat pipes. There is a double heat exchanger located midway the axial length of the panel. This heat exchanger has heat pipes that exit from both the top and bottom.

The last radiator concept configuration (D), has a number of telescoping panels. The heat pipes are parallel to the axis of the radiator. The gas heat exchanger is located at the top of each panel. The major problem with this design is the flexible joints that must seal the working fluid loop.

For this study, configuration (B) was selected for the 400-kW_e system. A combination of the features of (A) and (C) were used for the 100-kW_e layout.

2.2.2 Meteoroid Protection

The armor thickness is based on the equation shown on Figure 14. This information was supplied by JPL and includes the effect of operation in the Jovian environment. The number of failures is based upon the binomial distribution. For this study, it was found advantageous to design for a high probability of non-puncture. Table 3 lists shows the effect of non-puncture probability on armor thickness.

TABLE 3

THE EFFECT OF NON-PUNCTURE PROBABILITY ON ARMOR THICKNESS

Probability of Non-puncture of An Individual Tube	Percentage of Tubes Not Punctured*	Armor Thickness Ratio
0.85	83.5	1.000
0.90	88.8	1.134
0.95	94.1	1.397
0.99	98.6	2.242

*99 percent probability that no more than this percentage of tubes will be punctured. The specific design for the 400-kW_e system was based on 95 percent non-puncture.

- BASED ON PROTECTION FOR A SINGLE HEAT PIPE

$$t = C \left[\frac{AT}{-ln\,(P)} \right]^{0.2902}$$

WHERE t IS ARMOR THICKNESS, cm

C IS 0.00110 FOR LOCKALLOY

A IS VULNERABLE AREA, cm^2

T IS MISSION TIME, HOURS

P IS NO PENETRATION PROBABILITY

- NUMBER OF HEAT PIPE FAILURES BASED ON BINOMIAL DISTRIBUTION

$$P(i) = \sum_{m=0}^{i} \frac{P^m (1-P)^{n-m}\, n!}{m!\;(n-m)!}$$

P(i) IS PROBABILITY OF i OR FEWER PUNCTURES ($i \leqslant n$)

n IS TOTAL NUMBER OF HEAT PIPES

m IS NUMBER OF FAILED HEAT PIPES

Figure 14. Meteoroid Protection Criteria

It can be seen that increasing the non-puncture probability from 0.85 to 0.95 increases the armor thickness (and mass) by 40 percent. This is a worthwhile tradeoff when the major mass is the heat exchanger and heat pipes. If a low probability is selected, more heat pipes and heat exchanger mass must be added to compensate for the failed heat pipes. Excess heat transfer area on both the gas convection surface and the radiating surface will ensure that this radiator will function as designed when 6 percent of the tubes have failed.

2.2.3 Analytical Design

Analysis of the radiator utilizes a computer program. This program has been integrated into the cycle design program so that radiators can be designed at the same time the thermodynamic cycle is derived. Figure 15 summarizes the design method. Input from the cycle design program constitutes the major variables, such as:

- o Heat rejection rate
- o Flow
- o Temperature
- o Fluid properties
- o Pressure drop

Other input, which applies to the particular configuration to be studied, is read by the radiator program. This input includes:

- o Heat pipe diameter and wall thickness
- o Condenser length
- o Gas heat exchanger width
- o Heat transfer data
- o Armor model

With this input, the gas heat exchanger size and radiating area are calculated. The frontal area of the heat exchanger (and therefore

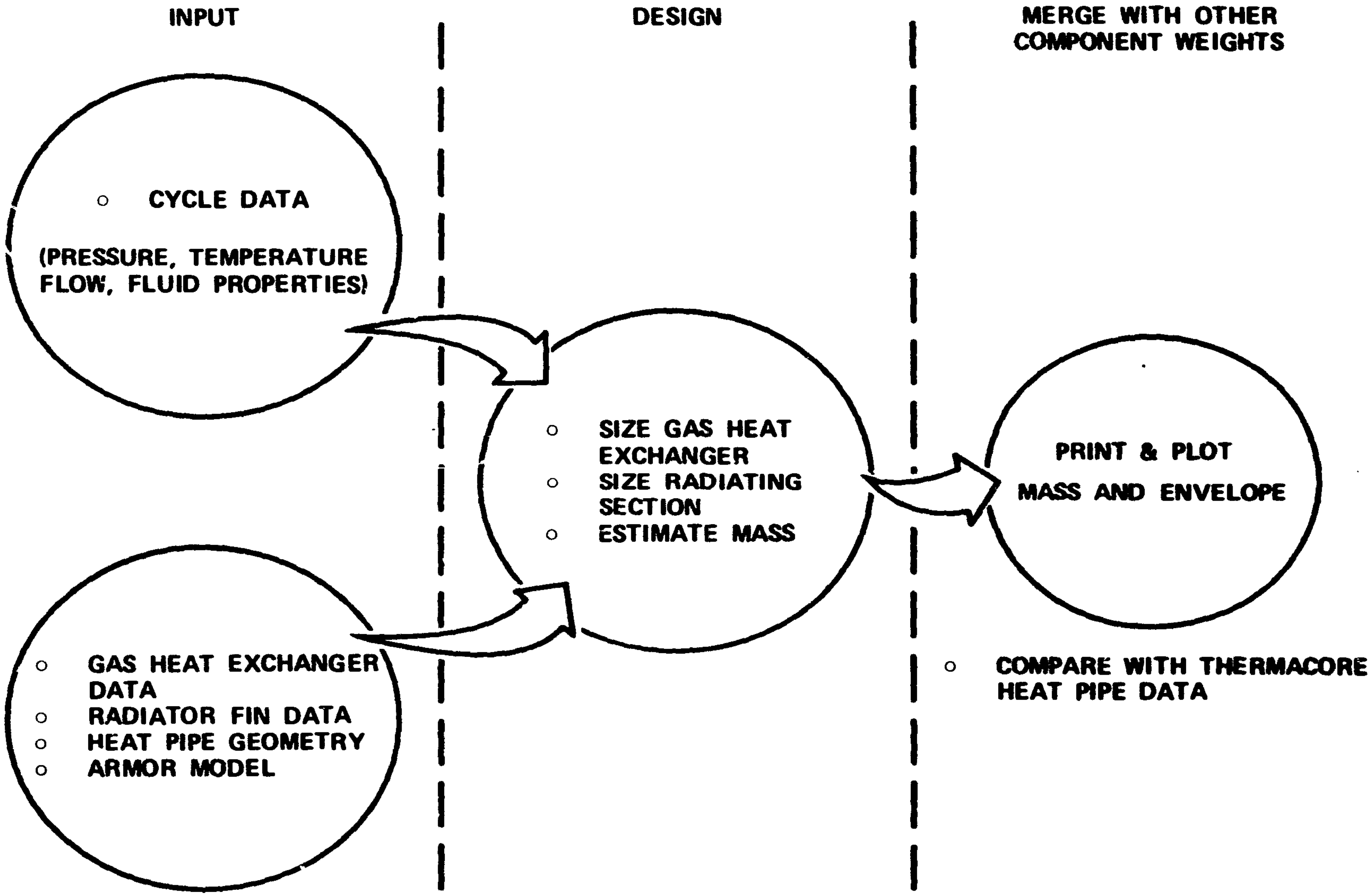


Figure 15. Radiator Design Method

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the evaporator length) is a function of the pressure drop. The heat transfer conductance has a strong effect on radiator size. The computer program calculates the length of the heat exchanger based on the conductance and radiating temperature. Evaporator length is changed as necessary to satisfy pressure drop. The program iterates until both heat transfer and pressure drop requirements are satisfied simultaneously.

When the calculation has converged, the mass of the radiator is calculated. This mass includes heat pipes, fin, armor, two gas-to-heat-pipe heat exchangers, and associated heat exchanger components (wrapup, headers, duct extension, and flanges).

The last step is to compare the computer heat pipe results with data on specific designs supplied by Thermacore. If the result is favorable, the conceptual design is accepted. If not, iteration is required.

2.2.4 Heat-Pipe Data

Appendix A includes the results of the Thermacore radiator heat pipe study (7). The important conclusions are:

- Rubidium is the preferred working fluid for 1 in. OD heat pipes when the temperature is above 650°K (710°F).
- Mercury is acceptable for temperatures as low as 550°K (530°F) if the heat-pipe diameter is less than 1 in. In fact, the power transferring capability of the heat pipe increased as the diameter decreased.
- Dowtherm A is the preferred fluid below 550°K (530°F) [minimum radiating surface temperature is 492°K (426°F)].
- Other advanced designs might offer increased performance and lower mass.

2.2.5 Advanced Heat-Pipe Concepts

A comparison of the performance characteristics of the evaporator and consenser sections of constant diameter heat pipes led to the conclusion that this type of heat pipe was not the optimum design. Thermacore agreed that it was possible to design and build heat pipes in which the evaporator diameter is greater than the condenser diameter. This results in a heat-pipe radiator in which the evaporation area is sufficient for convective heat transfer from the gas working fluid, and the condenser section is operated somewhat closer to the maximum heat transfer capability. The smaller heat-pipe condenser section minimizes vulnerable area and heat-pipe mass; consequently, armor mass is also minimized. This design concept reduced the radiator mass of the 400-kW_e reference system by 45 percent. Use of alternative advanced heat-pipe geometries may provide further substantial mass savings.

2.3 Task 3, Reference System Configuration and Component Conceptual Design

The overall reference system design concept is described in Section 2.1.3 above. The 400-kW_e spacecraft design that will fit in the Space Shuttle orbiter payload bay is shown in Figure 3 with major elements identified. The mass summary discloses the radiator to be, by far, the major mass element of the 8270-kg total mass. Further refinement of this heat-pipe radiator design and of the other components will permit appreciable reduction in the specific mass of 20.7 kg/kW_e.

2.3.1 Reference System Configuration

The configuration of the 400-kW_e Brayton power system is shown in Figure 16* with the nuclear subsystem farthest aft, away from the

*Approximate dimensions for the power conversion components may be scaled from the figure.

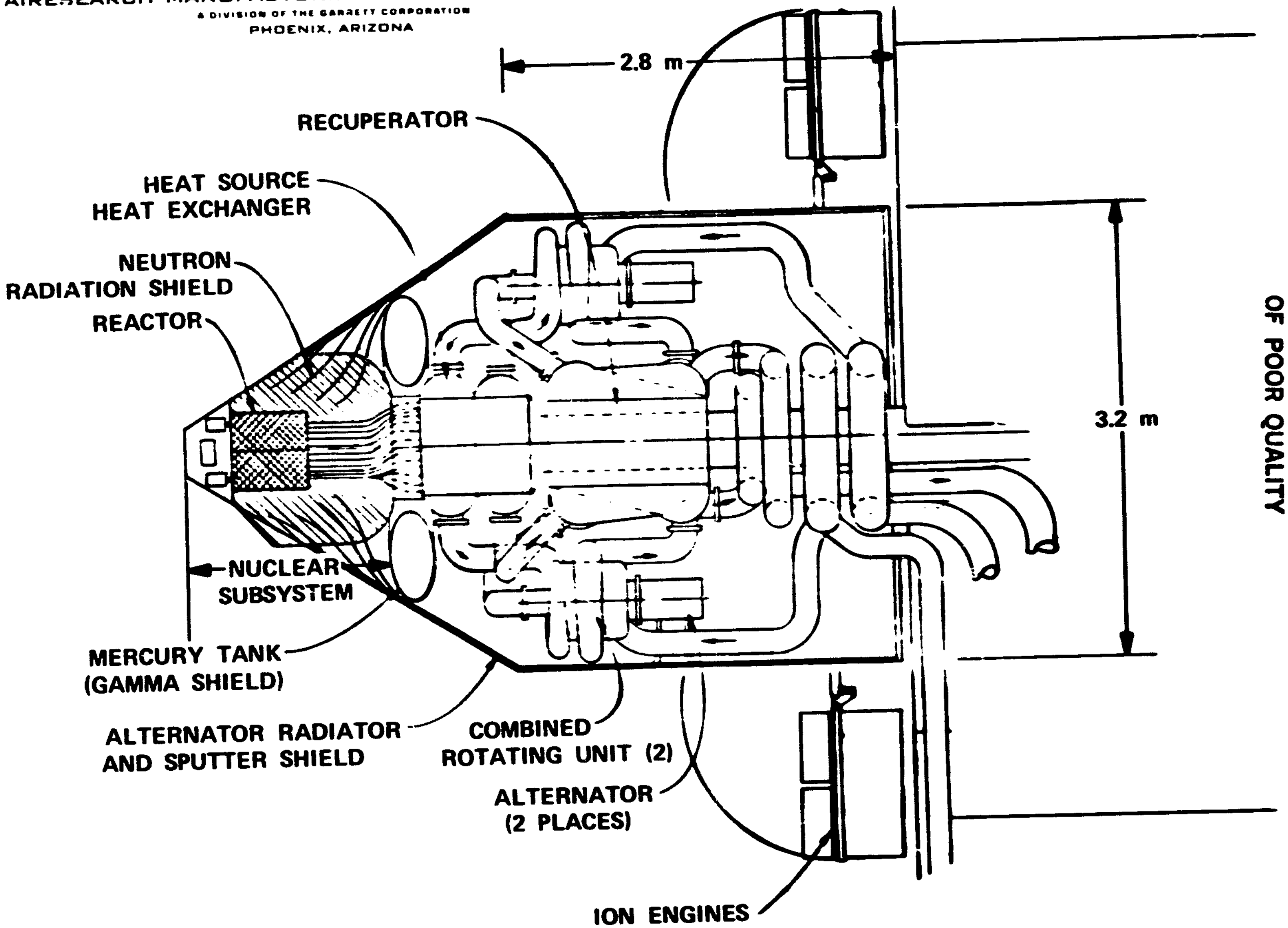

Figure 16. Configuration of 400-kW_e Brayton Power System For a Nuclear Electric Spacecraft.

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spacecraft, and the compactly clustered components of the two power conversion systems next to the panel-mounted ion engines. The cylindrical radiator encloses the spacecraft during launch and, thus, is between the spacecraft and the power system in the deployed configuration.

A schematic of the dual Brayton power systems used to eliminate the single-point failure mode in the nuclear electric spacecraft is given in Figure 17. Both completely independent systems, each of which is capable of producing 400 kW_e, are operated at half power under normal conditions. In the unlikely event that one of the systems becomes inoperable, the failed system is turned off and the pressure level doubled in the remaining system to restore full power output. Other means of assuring the required reliability for long durations are conceivable but the above method is preferred, at least until quantitative reliability and mass trade-off studies are accomplished.

Brayton cycle state points for the 400-kW_e reference system are given in Figure 18. The reactor with an outlet temperature of 1600°K provides the thermal energy to the heat source heat exchanger that provides the temperature rise from 1114 to 1500°K. The primary radiator provides the compressor inlet temperature of 500°K. The mass flow is 7.5 kg/sec.

2.3.2 Nuclear Subsystem

The nuclear subsystem configuration is delineated in Figure 19. The two major components are the reactor and its lithium hydride neutron shield. Controls, insulation, shield cooling heat pipes and radiator, and the mercury propellant tank, which serves as a gamma shield, are also shown in the figure.

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NOTE: DUAL FULL POWER CONVERSION
SYSTEMS ARE COMPLETELY INDEPENDENT

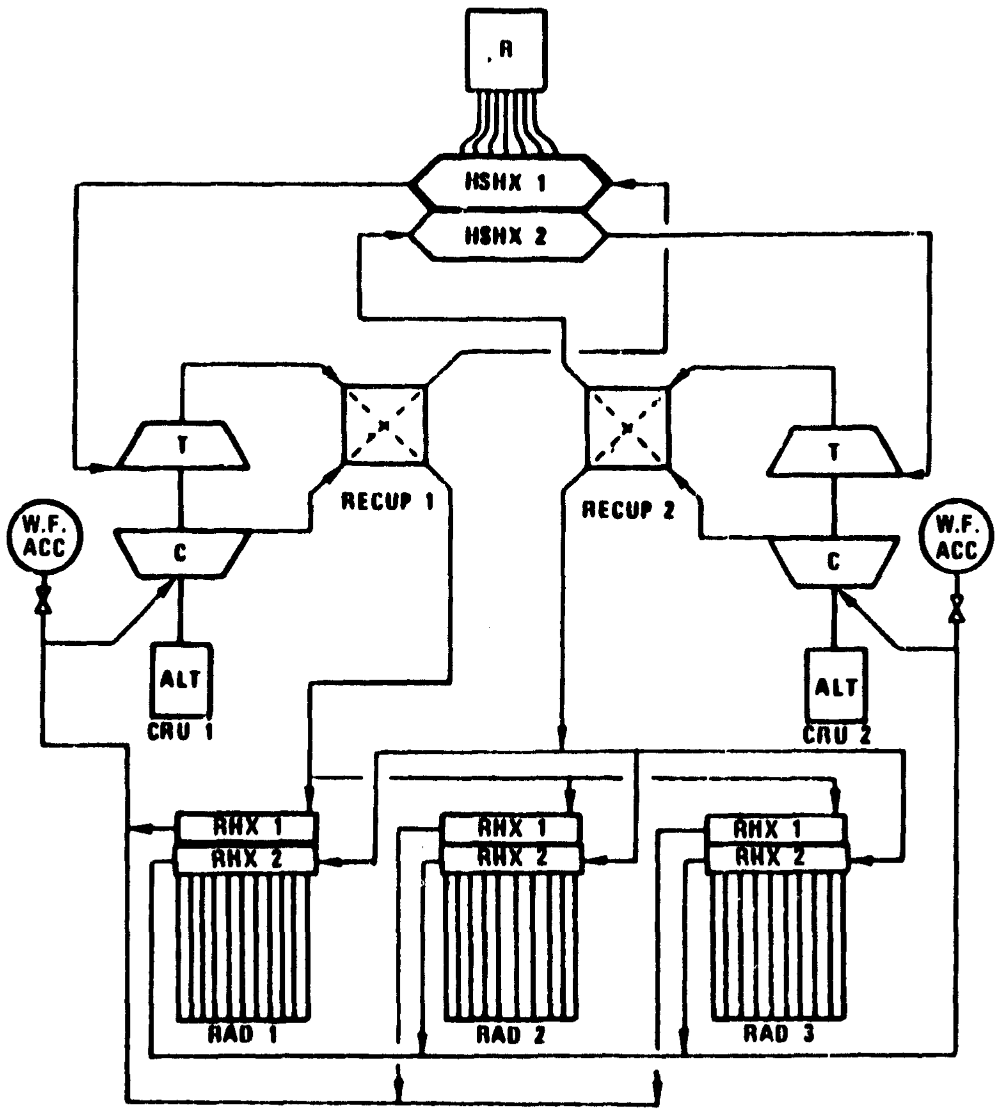

Figure 17. Nuclear Electric Spacecraft Dual Brayton Power Systems Schematic

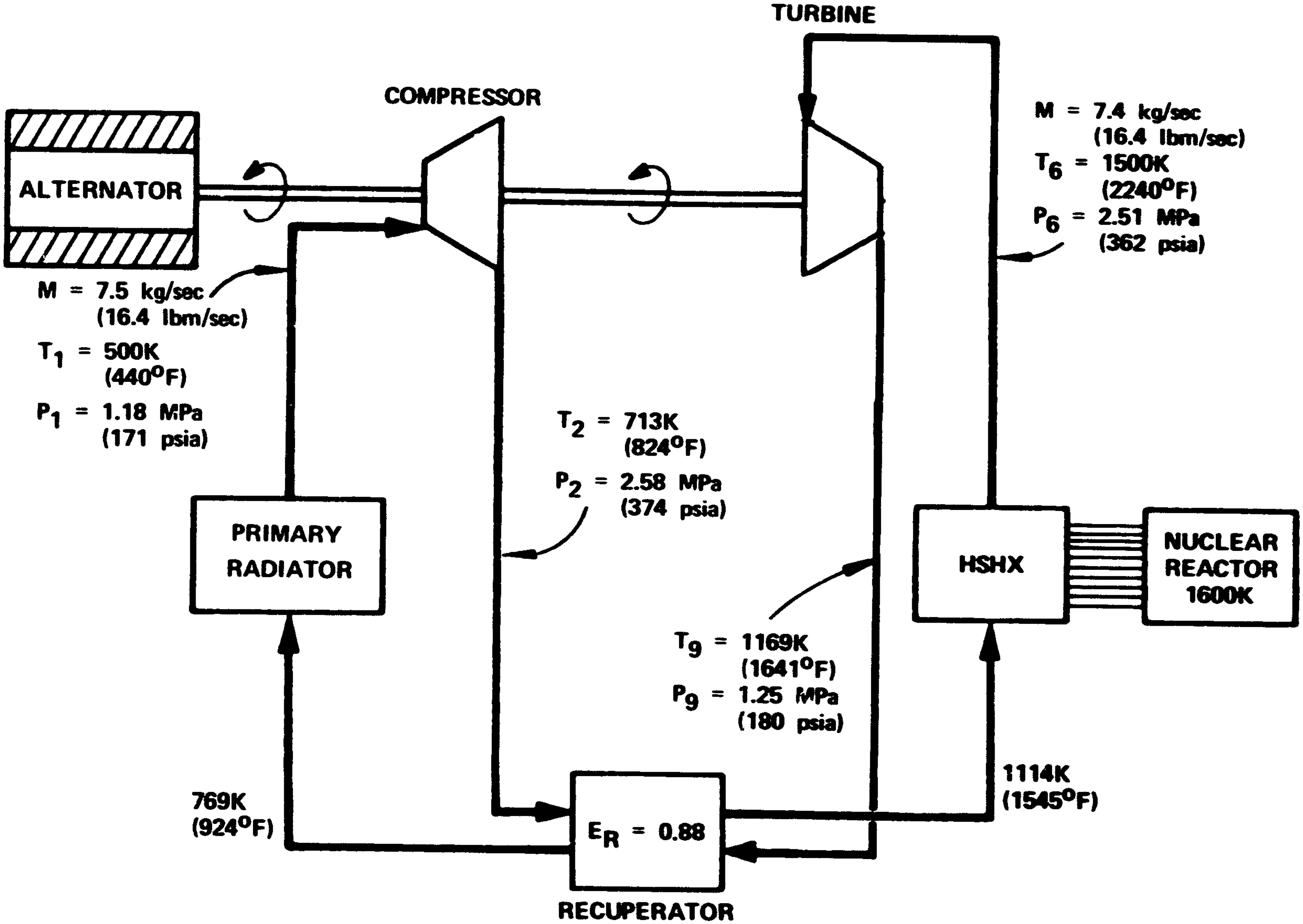

Figure 18. 400 kW_e Reference Power System Brayton Cycle State Points

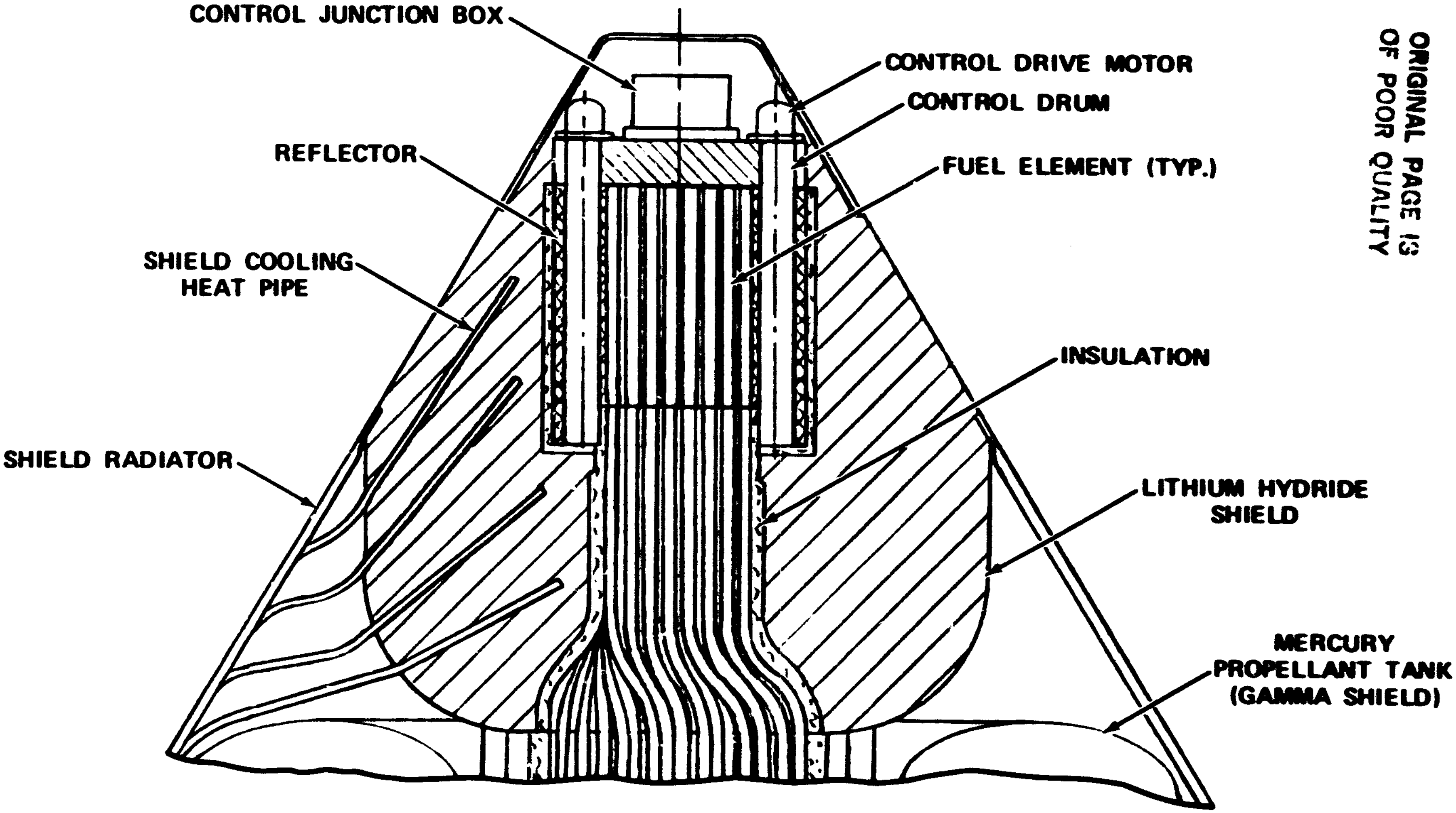

Figure 19. Space Nuclear Subsystem Reference Configuration

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The relation of heat-pipe cooled reactor characteristics to the characteristics of the nuclear subsystem are diagrammed in Figure 20. Preliminary determinations have been made of reactor and subsystem specific mass; the other characteristics remain for future analysis.

Reactors

LASL has provided parametric data on heat-pipe cooled reactors with uranium oxide (UO_2) and uranium carbide (UC) fuels. These data (8,9) are included in Appendix B. Data were also provided on gas cooled reactors (10) but they have not been used in this study. Characteristics of the nominal 1650-kW_t reactor selected for the 400-kW_e reference power system are shown in Table 4. The hexagonal fuel elements are made from a 60% UO_2-40% molybdenum mixture and have a central heat pipe for removing the thermal power. This reactor is a 0.6 m "square" cylinder with a total mass of 875 kg. The reactor specific mass is 0.53 kg/kW_t. The design concept for this LASL reference reactor is shown in Figure 21.

Another reference reactor with 400-kW_t nominal thermal power was identified for the preliminary conceptual design of the 100-kW_e power system with the characteristics listed in Table 5. This reactor has Uranium carbide-Zirconium carbide fuel elements. It has a 0.24-m diameter and a 0.24-m length, and a mass of 346 kg so that the specific mass is 0.87 kg/kW_t. The configuration of the 400-kW_t reactor can be seen in Figure 22 to be similar to the 1650-kW_t reactor.

LASL has recently published data on a new layered core heat-pipe cooled reactor design concept (11). The 1200-kW_t thermal power version is shown in Figure 23. Data on these new reactors have been made available too recently to be incorporated in this study although the layered core offers many improved characteristics. The reactor mass at 1200 kW_t is currently given as 470 kg for a specific mass of 0.39 kg/kW_t which should result in considerably improved system parameters.

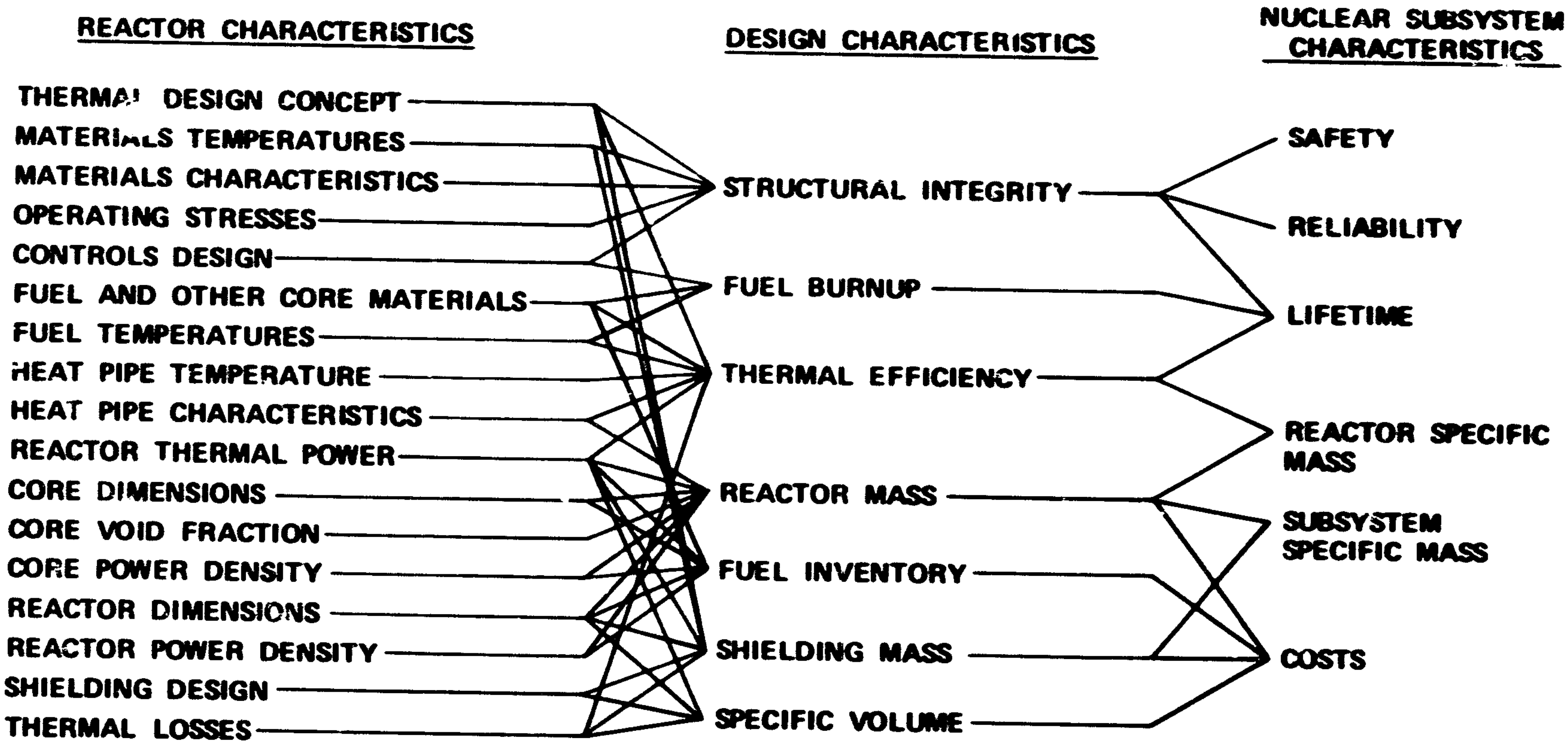

Figure 20. Relation of Heat Pipe Cooled Reactor Characteristics to Nuclear Subsystem Characteristics

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TABLE 4

LASL REFERENCE REACTOR CHARACTERISTICS - 1650 kW_t (nom.)

REACTOR TYPE	FAST SPECTRUM, HEAT PIPE COOLED
THERMAL POWER	1650 kW_t
LIFETIME	87.6 X 10^3 h
FUEL TYPE	UO_2 - Mo (60%)
FUEL ELEMENT CLAD	Mo
HEAT PIPE WALL/WORKING FLUID	Mo/Li
NO. OF FUEL ELEMENTS (AND HEAT PIPES)	210
FUEL ELEMENT WIDTH (ACROSS HEX. FLATS)	0.0246 m
FUEL ELEMENT LENGTH	0.3756 m
MAXIMUM FUEL TEMPERATURE	1696 K
AVERAGE POWER IN FUEL SPACE	53 MW_t/m^3
FISSION DENSITY	4.968 X 10^{20} FISSIONS/cm^3
FUEL SWELLING	1.11 VOLUME %
FUEL (^{235}U) BURNUP	4.6 ATOM %
CORE DIAMETER	0.3756 m
CORE LENGTH	0.3756 m
CORE VOLUME	0.042 m^3
CORE VOID FRACTION	0.328
CORE POWER DENSITY	39.3 MW_t/m^3
REFLECTOR MATERIAL	Be, BeO
STRUCTURAL MATERIAL	Mo
REACTOR DIAMETER	0.6056 m
REACTOR HEIGHT	0.5856 m
REACTOR VOLUME	0.169 m^3
REACTOR POWER DENSITY	9.76 MW_t/m^3
REACTOR OUTLET (HEAT PIPE) TEMPERATURE	1600 K
REACTOR MASS SUMMARY, kg	
FUEL (^{235}U MASS = 150.6 kg)	275
REFLECTOR	322
HEAT PIPES (112.24 kg/m)	166
CONTROL SYSTEM	33
SUPPORT STRUCTURE	57
TOTAL MASS	875
REACTOR SPECIFIC MASS	0.530 kg/kW_t

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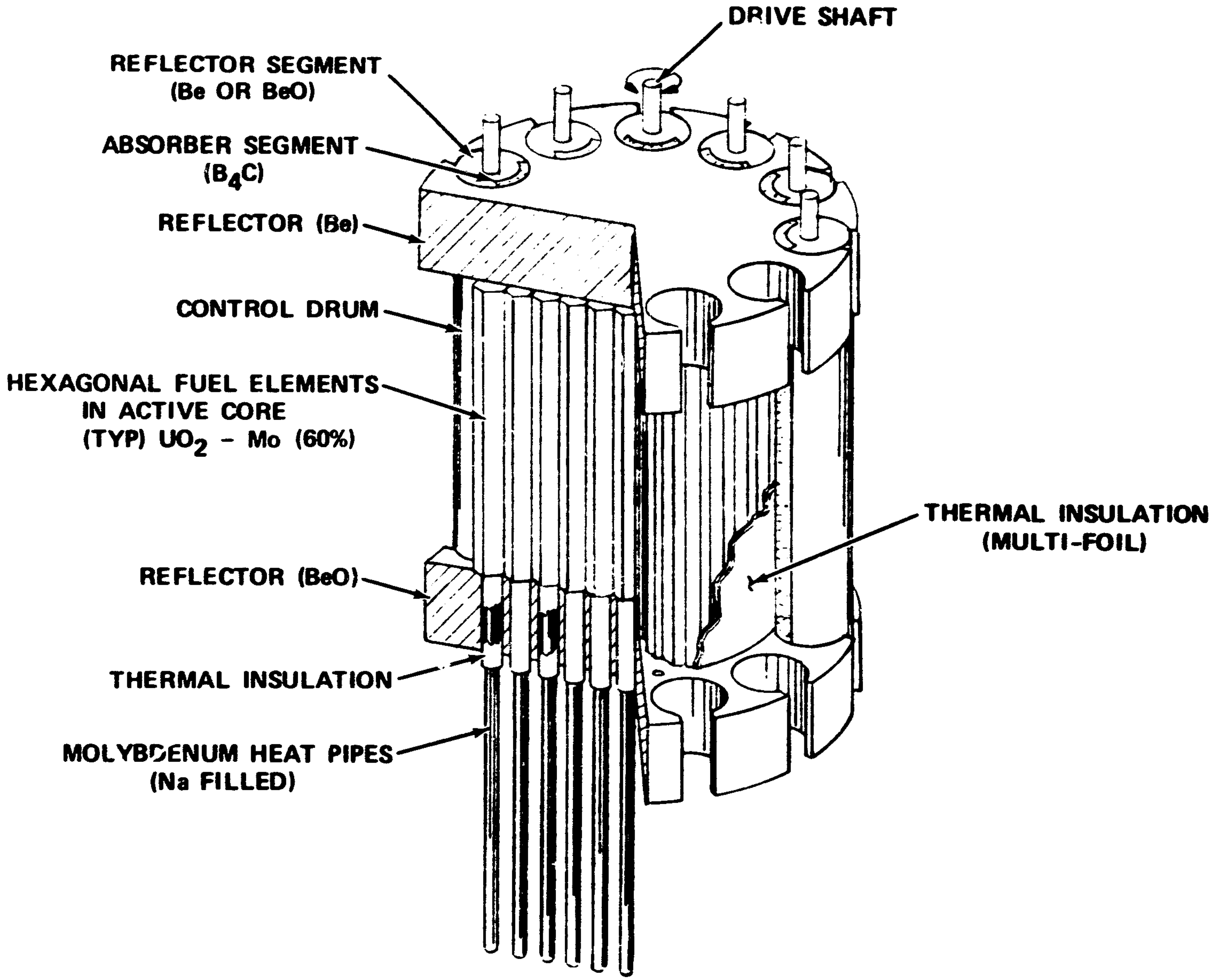

Figure 21. LASI Reference Reactor Design Concept - 1650 kW_t (nom.)

TABLE 5

LASL REFERENCE REACTOR CHARACTERISTICS - 400 kW_t (nom.)

REACTOR TYPE	FAST SPECTRUM, HEAT PIPE COOLED
THERMAL POWER	400 kW_t
LIFETIME	87.6 X 10^3 h
FUEL TYPE	UC - ZrC
FUEL ELEMENT CLAD	Mo
HEAT PIPE WALL/WORKING FLUID	Mo/Li
NO. OF FUEL ELEMENTS (AND HEAT PIPES)	84
FUEL ELEMENT WIDTH (ACROSS HEX FLATS)	0.0246 m
FUEL ELEMENT LENGTH	0.2381 m
MAXIMUM FUEL TEMPERATURE	1554.2 K
AVERAGE POWER IN FUEL SPACE	47.83 MW_t/m^3
FISSION DENSITY	4.474 X 10^{20} FISSIONS/cm^3
FUEL SWELLING	6.44 VOLUME %
FUEL BURNUP	2.15 ATOM %
CORE DIAMETER	0.2381 m
CORE LENGTH	0.2381 m
CORE VOLUME	0.0106 m
CORE VOID FRACTION	0.3295
CORE POWER DENSITY	37.74 MW_t/m^3
REFLECTOR MATERIAL	Be, BeO
STRUCTURAL MATERIAL	Mo
REACTOR DIAMETER	0.4681 m
REACTOR LENGTH	0.4481 m
REACTOR VOLUME	0.0771 m
REACTOR POWER DENSITY	5.188 MW_t/m^3
REACTOR OUTLET (HEAT PIPE) TEMPERATURE	1425 K
REACTOR MASS SUMMARY, kg	
FUEL (^{235}U MASS = 78.2)	92.0
REFLECTOR	162.1
HEAT PIPES	36.5
CONTROLS	33.0
SUPPORT STRUCTURE	22.7
TOTAL MASS	346.3
REACTOR SPECIFIC MASS	0.866 kg/kW_t

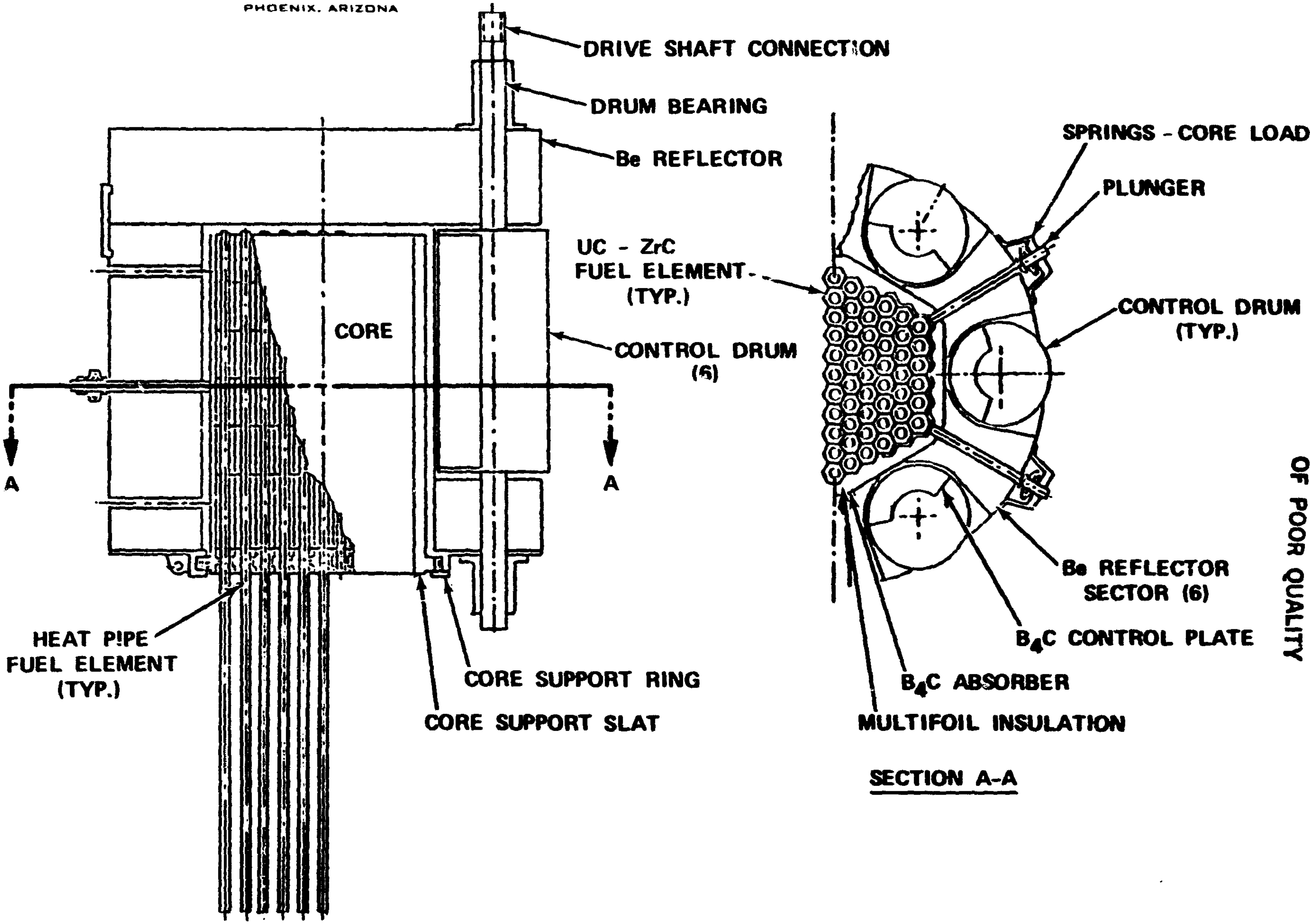

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Figure 22. LASL Reference Reactor Design Concept - 400 kW_t (nom.)

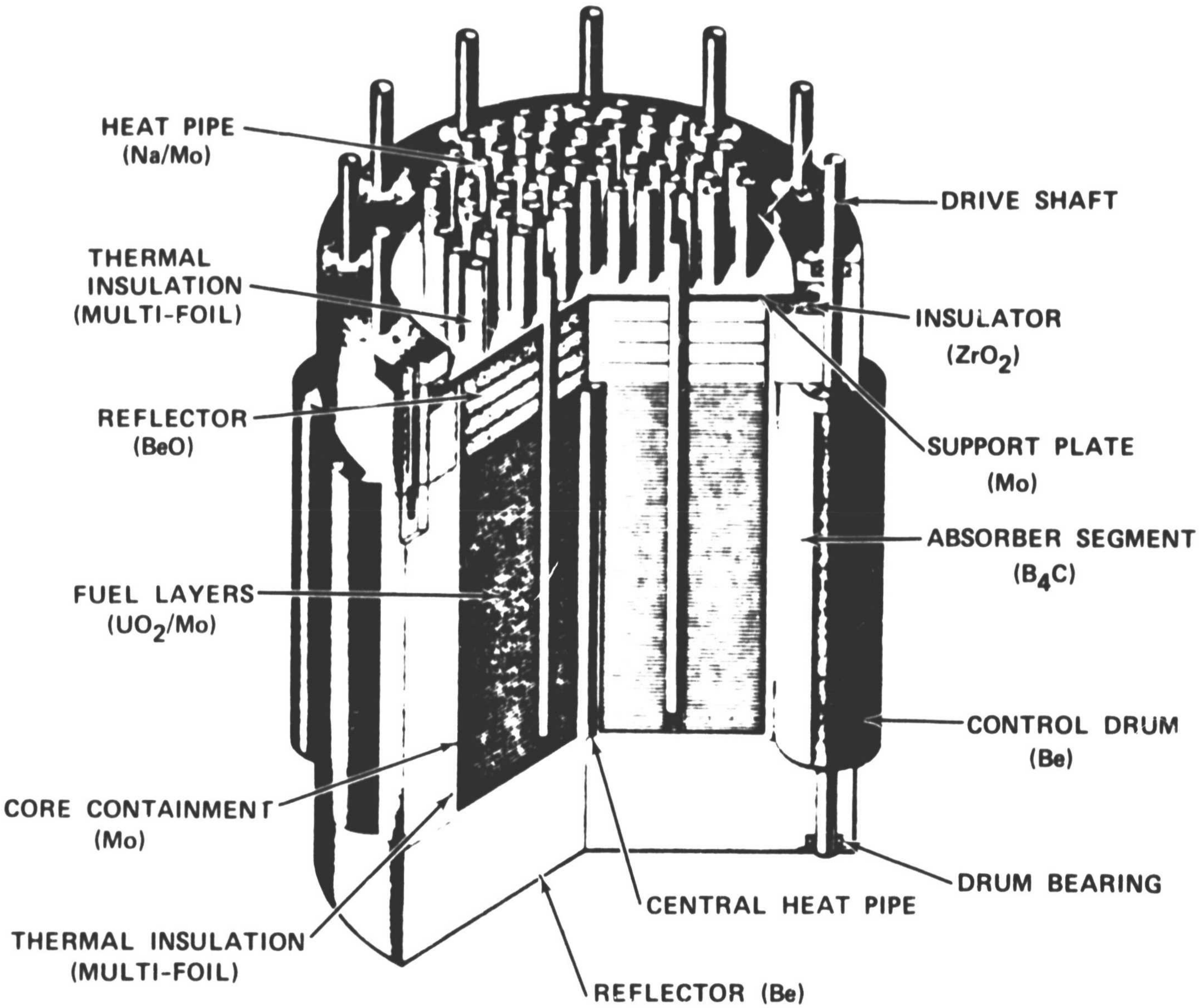


Figure 23. LASL Layered Core Heat Pipe Cooled Space Power Reactor Design Concept - 1200 kW_t

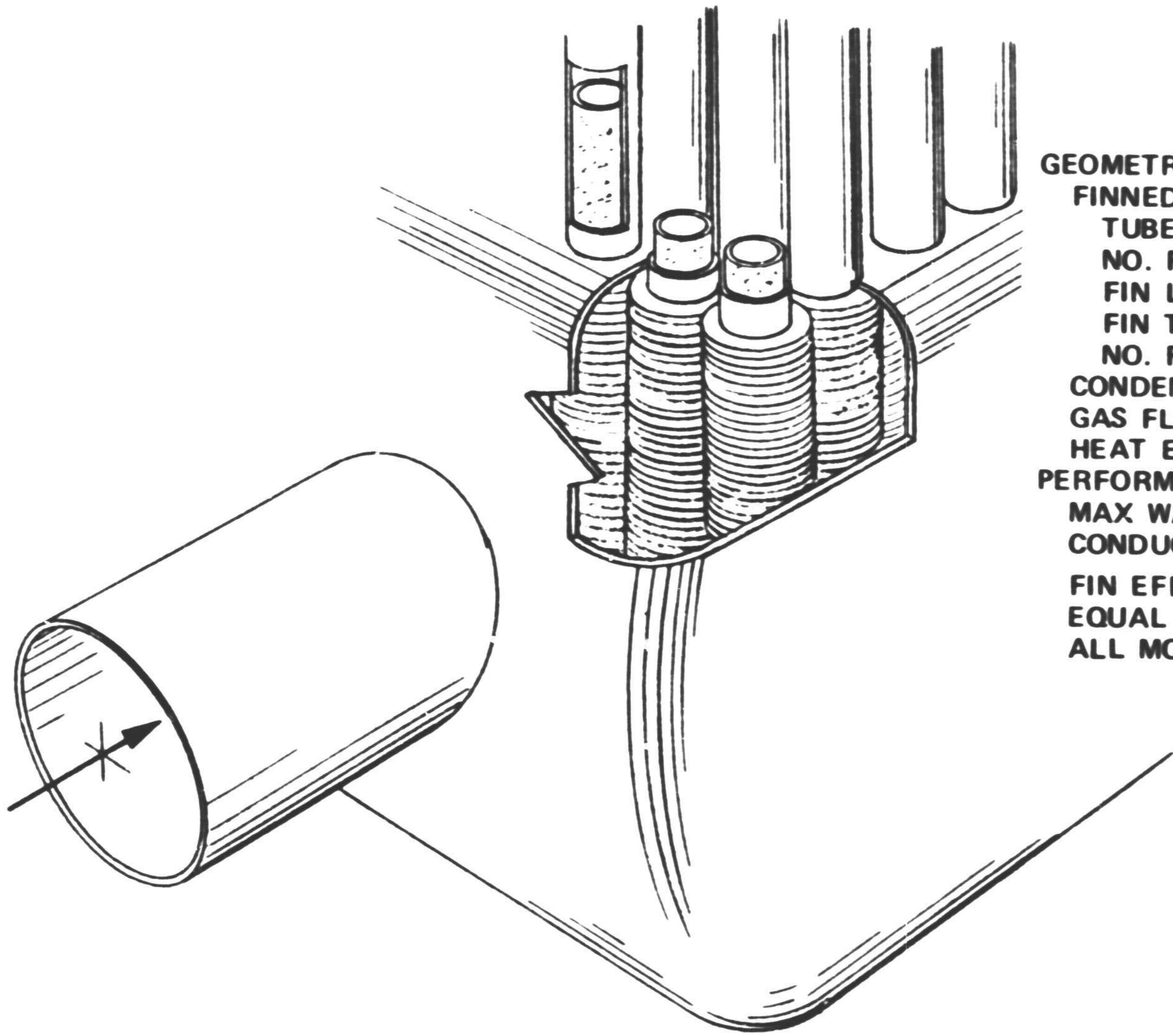
Radiation Shields

The nuclear radiation shielding has not been given detailed attention since the requirement is similar to the design used for the thermionic systems. Tailoring of the lithium hydride neutron shield to reduce its mass is shown in Figure 19. The propellant tank is located so that it can be used as a gamma radiation shield and is sized to hold an additional quantity of mercury for this purpose.

2.3.3 Heat Source Heat Exchanger

The heat source heat exchanger (HSHX) is the highest temperature component of the closed cycle system(s). This component looks like a typical tube fin heat exchanger and is illustrated in Figure 24. The geometry and performance are also summarized on this chart. The operation differs from a normal heat exchange because this design has equal heat flux from each tube. This occurs because each tube is actually the condensing end of a heat pipe. The heat pipe receives its heat in the nuclear reactor and gives it up in the heat exchanger. The heat is transferred to the working fluid by convection from the heat pipes and fins. In the reference system, the HSHX receives working fluid from the recuperator at 1114°K and provides it to the turbine at 1500°K.

There is a heat source heat exchanger for each power system. Because of the nature of heat pipes, when each evaporator section is operated at half power(the nominal operation), the maximum metal temperature is reduced from the 1583°K (the value when only one section is in use). This heat exchanger is all-molybdenum construction. This material is also used in the heat pipes.



CHARACTERISTICS

GEOMETRY:
- FINNED TUBE
  - TUBE OD = 2.5 cm (1 in.)
  - NO. FIN/cm = 10 (25 fins/inch)
  - FIN LENGTH = 0.5 cm (0.2 in.)
  - FIN THICKNESS = 0.25 mm (0.010 in.)
  - NO. FINNED TUBES = 162
- CONDENSING LENGTH = 41.2 cm (16.2 in.)
- GAS FLOW LENGTH = 67.8 cm (26.7 in.)
- HEAT EXCHANGER WIDTH = 33.0 cm (13 in.)

PERFORMANCE
- MAX WALL TEMPERATURE = 1583^{o}K (2390^{o}F)
- CONDUCTANCE = 21 kW$_t$/^{o}K (11Btu/sec-^{o}F)
- FIN EFFECTIVENESS = 67 PERCENT
- EQUAL HEAT FLUX PER TUBE
- ALL MOLYBDENUM CONSTRUCTION

Figure 24. Heat Source Heat Exchanger Concept and Characteristics

2.3.4 Combined Rotating Unit

The combined rotating unit (CRU) is a highly efficient, single shaft, closed Brayton cycle design that has resulted from many years of development and test in industry and government, especially under NASA sponsorship. Figure 25 is a rendering of the engine. The three primary components are the compressor, turbine, and alternator.

The compressor is a state of the art design. It is radial outflow type with backward curved blades for maximum efficiency. The turbine is the radial inflow type with straight radial blades. It is also state of the art aerodynamic design.

Both the compressor and turbine are relatively small wheels. Moderate specific speed and relatively high Reynolds number result in high component efficiency. The actual design parameters are shown in Table 6.

Prior experience indicates that the CRU bearings are one of the most critical components for a long life space power system. The alternator is mounted on one pair of foil journal bearings. The compressor and turbine are mounted on a larger pair of similar bearings. Two sets of foil thrust bearings absorb the aerodynamic thrust of the compressor and turbine. Foil-type gas-lubricated bearings are designed such that all excursions are absorbed by a film of gas, which together with the foil, has a definable spring constant. With proper design, the rotor does not contact any bearing surface after it achieves a small fraction of the normal rotational speed during start. Because nothing rubs, there is no wear-out mode.

The alternator has a high performance samarium cobalt rotor. This rotor is smaller and lighter than a Rice alternator. Because it is smaller, the windage loss is much smaller. The alternator has the following performance:

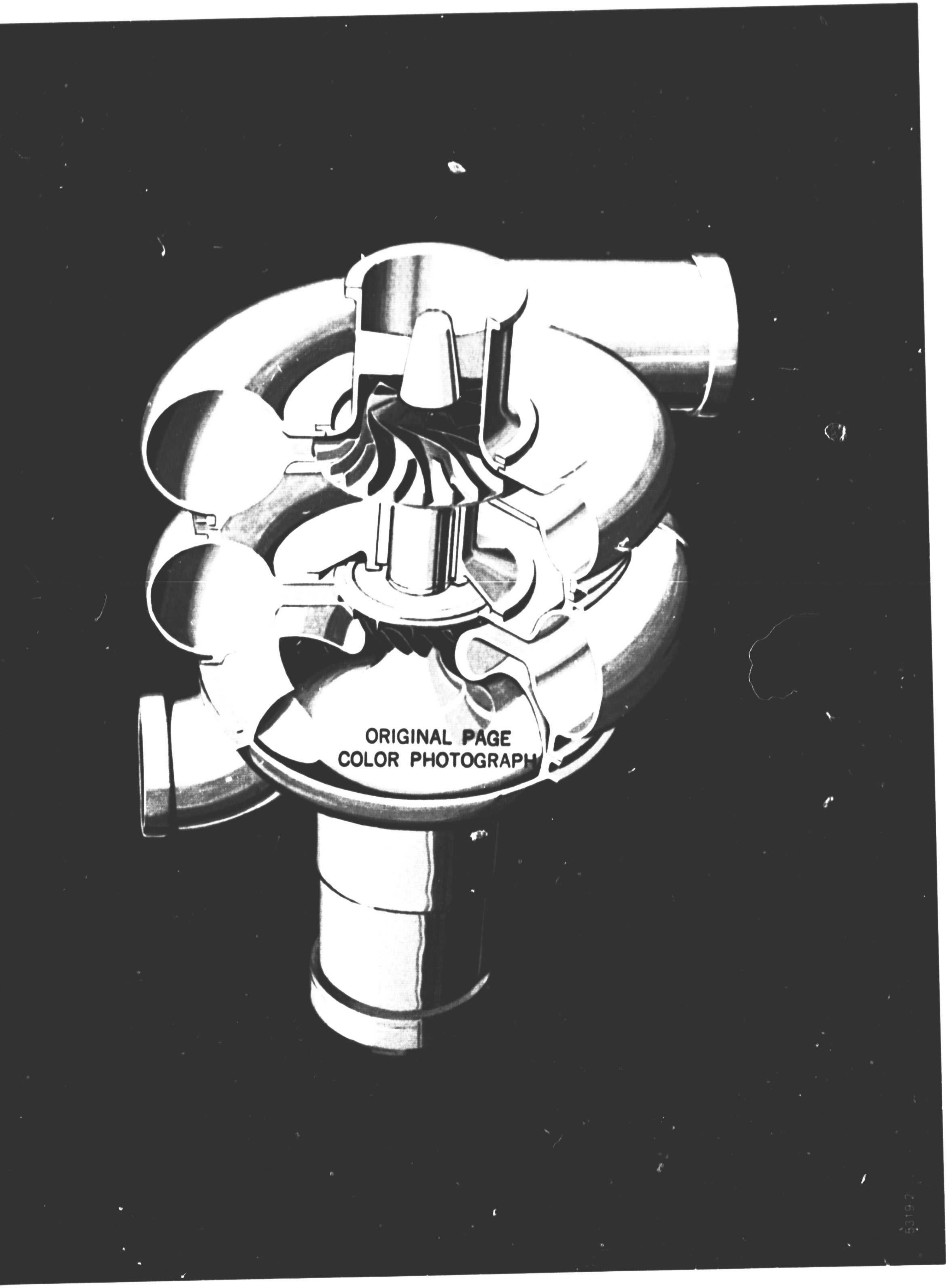

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TABLE 6

TURBINE AND COMPRESSOR WHEEL CHARACTERISTICS

	Turbine	Compressor
Pressure Ratio	2.01	2.18
Tip Speed	440 m/sec (1440 ft/sec)	400 m/sec (1300 ft/sec)
Mean Specific Speed	62.0 rpm-ft$^{3/4}$/sec$^{1/2}$	58.5 rpm-ft$^{3/4}$/sec$^{1/2}$
Tip Diameter	23.4 cm (9.2 in.)	21 cm (8.3 in.)
Reynolds Number	380,000	24 x 10^6
Mass	11.4 kg (25 lb) Refractory or Advanced Superalloy	2.7 kg (6 lb) Titanium
Efficiency	91 Percent	86 Percent
Comments	o State of the art aero dynamic design o Relatively small wheel with low tip speed	o High efficiency because of low pressure ratio, moderate specific speed and Reynolds number o Low risk aerodynamic design

Efficiency	96% without windage
Output	408 kW_e
Frequency	3000 Hz
Voltage	500 Line-to-Neutral

The alternator is mounted adjacent to the compressor rather than the turbine so that it has a lower temperature environment. The alternator is cooled by heat pipes. The heat is dumped by the alternator heat pipe radiator.

2.3.5 Recuperator

The recuperator is the component which enables the high efficiency of closed Brayton cycle engines. It exchanges the heat from the turbine discharge gas to the colder gas leaving the compressor. Extensive recuperation leads to relatively low-pressure ratios in the turbomachinery. Low-pressure ratio yields simple, highly efficient compressors and turbines. The mass of the turbomachinery is also reduced. All of these beneficial results require increased recuperator mass. Shotgun plots such as Figures 5 through 12 illustrate this effect, revealing the best combination of components to be selected for each application.

The recuperator is shown in Figure 26. It is a pure counter flow design to minimize mass. Each flow is split and moves through alternate finned passages. The heat from the turbine discharge gas is exchanged by convection to the fin and wall and thence to the other gas stream. Each stream is completely sealed from the other.

The selected recuperator uses a conventional fin design of 8 fins/cm (20 fins/in.). The heat transfer data were derived from AiResearch development testing. Similar finning is used in present production units. The computer code uses this data together with the

CHARACTERISTICS

EFFECTIVENESS = 88%
WELL WITHIN STATE-OF-THE-ART
TOTAL PRESSURE DROP ($\Delta P/P$) = 1.6%
OVERALL LENGTH = 48 cm (19 INCHES)
HEIGHT = 79 cm (31 INCHES)
WIDTH = 41 cm (16 INCHES)
MASS = 365 kg (805 lb_m)
HEAT TRANSFER RATE = 1552 kW_t (1471 BTU/SEC)
MATERIAL - HOT END MUST BE REFRACTORY (Cb)
- COLD END COULD BE SUPERALLOY (HAST-X)
OTHER ASSEMBLY OPTIONS
- REFRACTORY HEAT PIPE HOT END, HAST-X
USED AT TEMPERATURES BELOW 1033°K (1400°F)

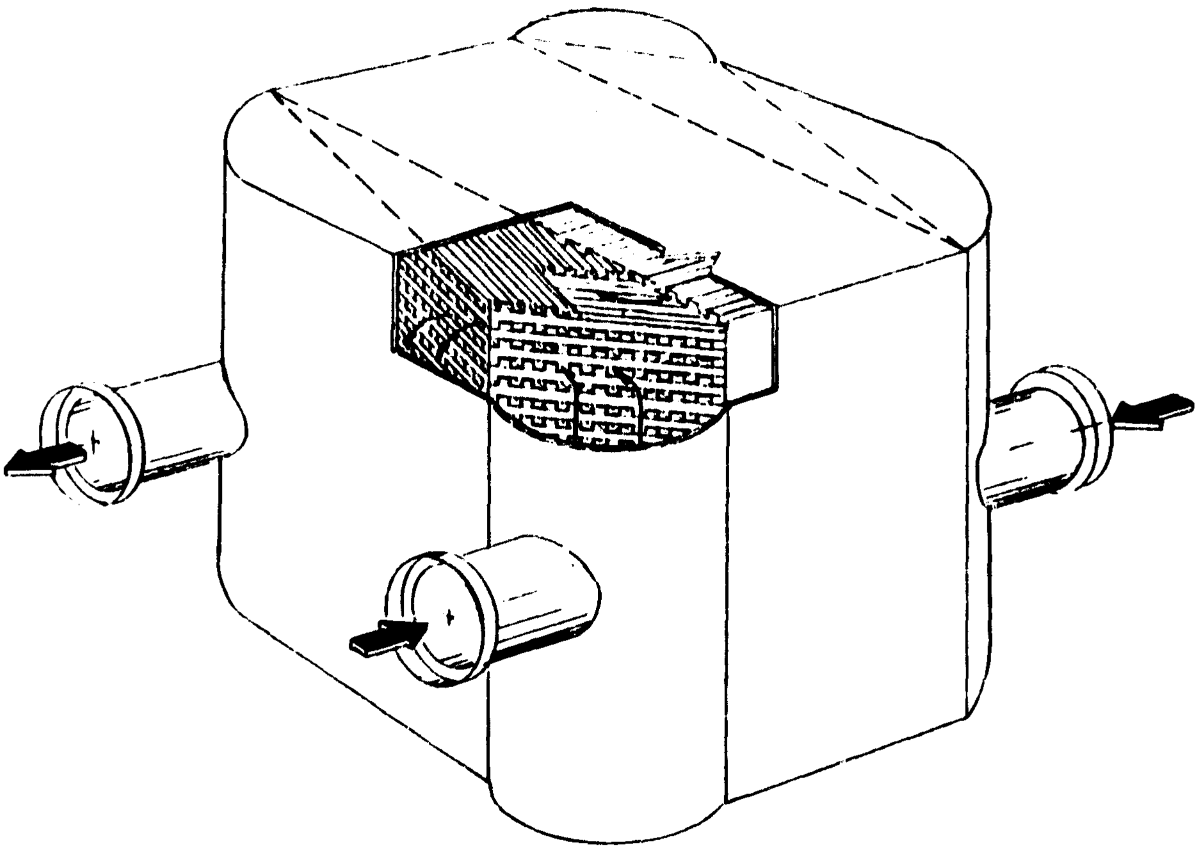

Figure 26. Recuperator Design Concept and Characteristics

gas properties, state point, and desired effectiveness and pressure drop to calculate the geometry and mass of this heat exchanger.

Each recuperator has a mass of 365 kg (805 lb). The effectiveness of 88 percent is easily within the state of the art. (Effectiveness defines the percentage of heat available from the turbine exhaust gas which is transferred to the compressor discharge gas.) The design is compact, with dimensions shown on Figure 26. The only area needing development is manufacturing technology. Analytical study is needed to define the assembly method. The refractory materials are well-characterized, but some work is needed to demonstrate joining techniques. Other heat exchange/manufacturing options are available and should be explored.

2.3.6 Heat-Pipe Radiator Design

The heat-pipe radiator is the largest and most massive component in the power system. This radiator rejects the fraction of the input heat that is not converted to electricity to the sink of space. Figure 27 illustrates the heat balance for the entire system. The geometry of the radiator is defined by the closed cycle engine design program. This geometry is a function of heat rejection rate, compressor inlet temperature, pressure drop, and flow rate. This radiator was designed to fit into the Space Shuttle bay.

The cylindrical radiator is composed of eight identical panels. The amount of bending of the heat pipes required to yield the cylindrical geometry has no deleterious effect on the heat-pipe performance, according to Thermacore. The manner in which these panels overlap is shown in Figure 28. The gas heat exchanger of each radiator is protected from micrometeoroid penetration by the overlapping heat pipes from the adjacent panel. A multifoil insulation blanket is also sandwiched between the gas heat exchanger and heat rejection panel to provide thermal isolation and additional micrometeoroid protection.

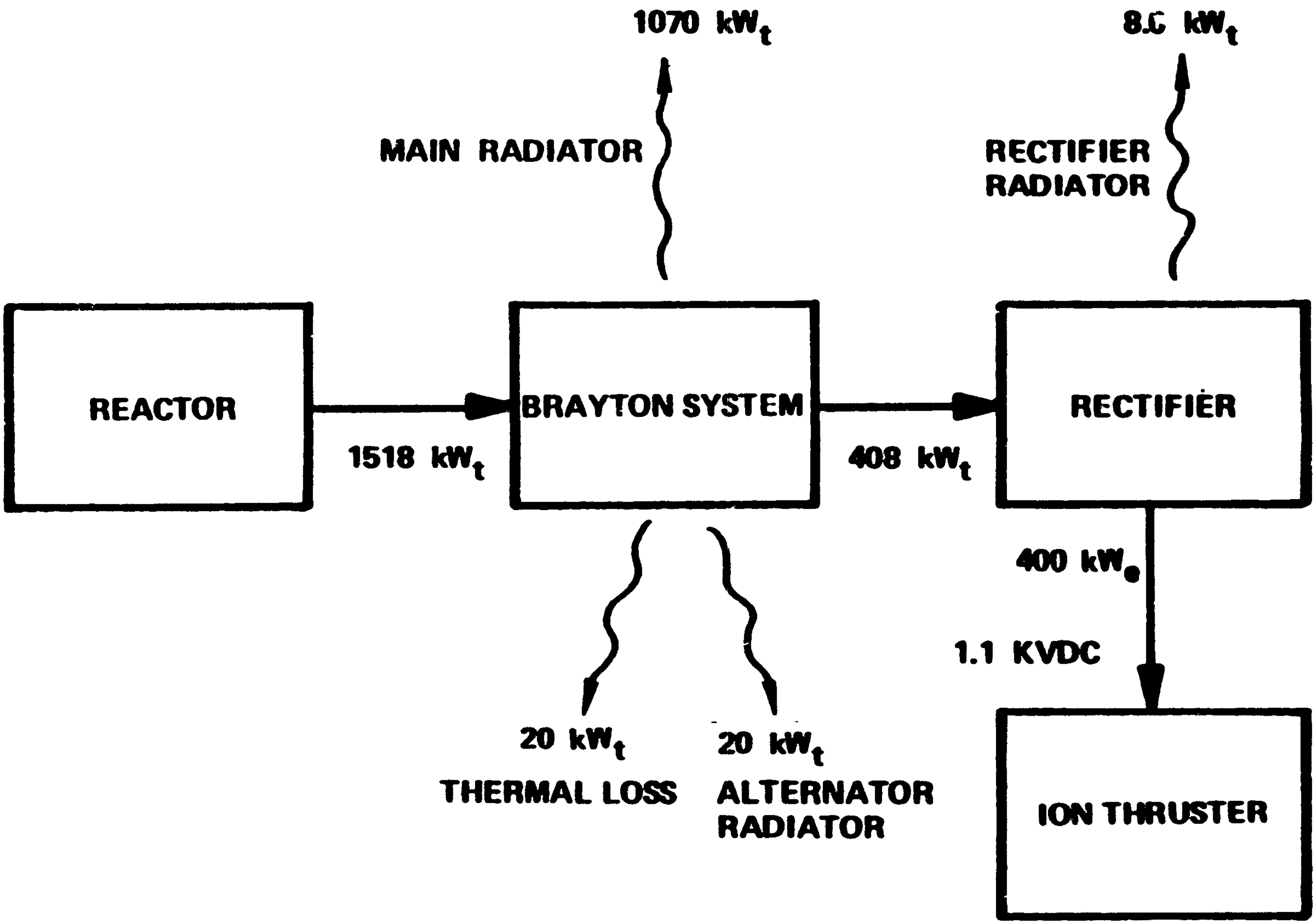

Figure 27. Heat Balance for 400-kW_e Brayton Power System.

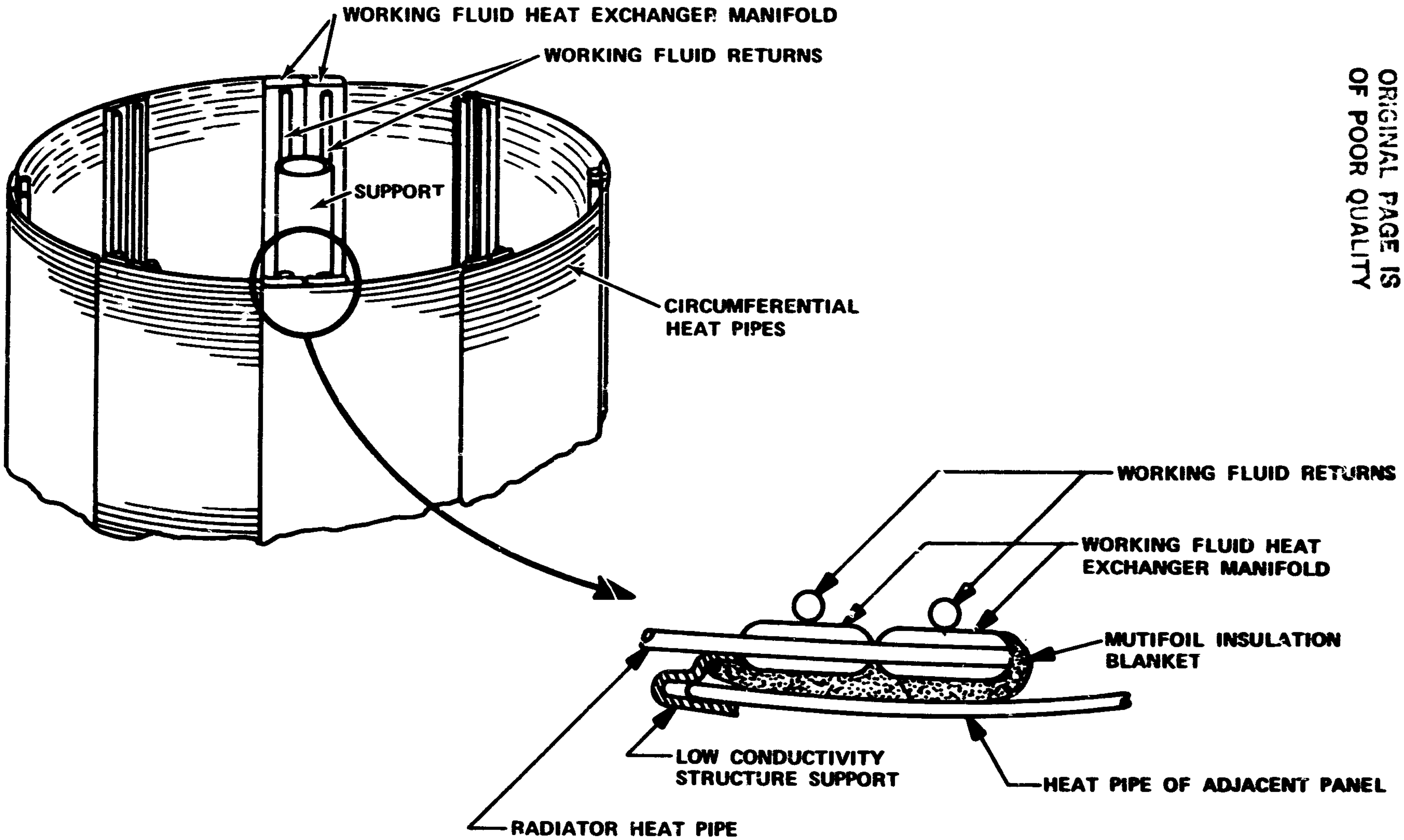

Figure 28. Cylindrical Heat Pipe Radiator Conceptual Design

Figure 29 is an illustration of the heat-pipe radiator that shows the gas heat exchanger, heat pipes, and fin. There are two gas heat exchangers, either of which can carry the entire thermal load to the heat pipes. When both redundant power systems are operated at half power, each heat exchanger carries half of the thermal rejection load. In any event, the radiator panel always carries the entire thermal load.

Figure 29 also lists the performance of the hot-end and cold-end heat pipes as well as the geometry of the gas heat exchanger. Diameter of the evaporator heat pipes is 2.5 cm (1 in.) to achieve adequate gas-side heat transfer area. The diameter of condenser heat pipes varies from 0.6 to 1.3 cm. This use of dual diameters greatly reduces the mass of armor from that which otherwise would have been required. The mass of the heat pipes is also reduced.

As the data in Appendix A show, the smaller diameter heat pipes have adequate heat-transfer capacity with reasonable temperature drop down the pipe. Clearly, a larger diameter heat pipe would have a greater heat transfer capacity. While analytical methods have not been fully characterized for a tapered pipe (e.g., a large diameter evaporator coupled to a smaller diameter condenser with a short tapered transition), such pipes have been fabricated and tested. Thermacore has concurred that this approach is basically sound and that there should be very little uncertainty of the feasibility of such a pipe.

A mass summary for the radiator is given in Table 7. The two largest contributors are the gas heat exchanger and heat pipes. Some mass reduction in the heat pipes is possible if thinner walls are used (the present design has a wall thickness of 3 to 6 percent of diameter). Mass reduction is also possible with the new armor design being investigated by Thermacore. Furthermore, the mass of the gas heat exchanger could be reduced by use of composite materials. Some

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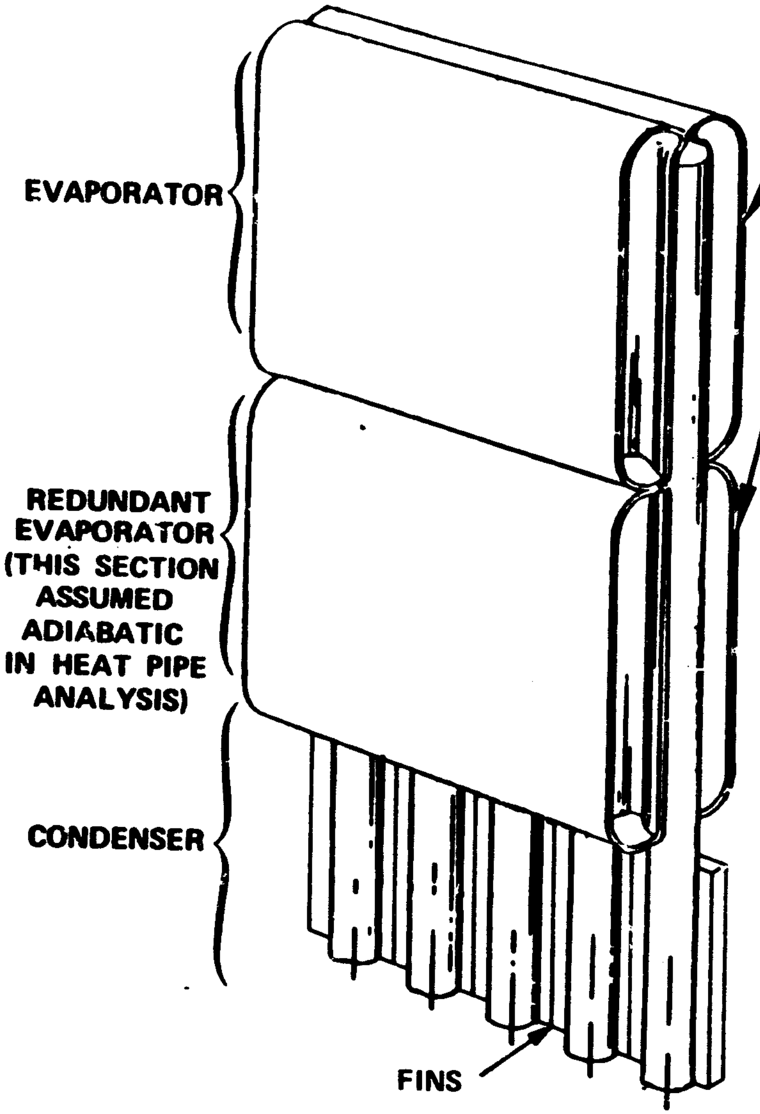

	HOT END	COLD END
GAS TEMPERATURE	770K	500K
RADIATING TEMPERATURE	691K	484K
WORKING FLUID	RUBIDIUM OR MERCURY	DOWTHERM A
HEAT REJECTION/HEAT PIPE	1.0 kW_t	0.23 kW_t
EVAPORATOR FLUX	5 W_t/cm^2	1 W_t/cm^2
NUMBER OF HEAT PIPES PER PANEL	170	105
HEAT PIPE DIAMETER	0.6 cm	1.3 cm

NUMBER OF PANELS	8
GAS REYNOLDS NUMBER	85700
RADIATOR FIN EFFECTIVENESS	0.98
RADIATOR SURFACE EMISSIVITY	0.90
FIN THICKNESS	0.25 cm
FIN LENGTH	[illegible].25 cm
EVAPORATOR LENGTH	[illegible] cm
CONDENSER LENGTH	[illegible]6.0 cm
HEAT EXCHANGE WIDTH	5.6 cm
EVAPORATOR HEAT PIPE DIAMETER	2.5 cm
CONDUCTANCE	3.8 kW_t/K
CONDUCTANCE MARGIN	20%

Figure 29. Heat Pipe Radiator Heat Exchanger Design Concept and Characteristics.

TABLE 7

MASS SUMMARY FOR RADIATOR WITH DUAL-DIAMETER HEAT PIPES

Component	Mass, kg
Evaporator Heat Pipes	766
Heat Exchanger Wrap Up	1433
Condenser Heat Pipes	650
Armor	439
Fins	752
Total	4040

slight reduction in fin mass is also possible. Summing these contributions would result in a total radiator mass of less than 3800 kg. This would reduce the system specific mass (Jovian environment) to 20 kg/kW_e.

Stainless steel was selected for the heat pipes because of its compatibility with the heat pipe working fluids. Steel was also selected for the gas heat exchanger because of its strength to weight ratio. Beryllium or Lockalloy (Be38Al) was selected for the armor because of its low density, high modulus of elasticity and high thermal conductivity. Either of these materials could also be used for the fin because of low density and high conductivity.

2.3.7 Power Conditioning and Associated Heat Rejection

The power conditioning is accomplished by a solid state device which converts 500 VAC line to neutral to 1100 VDC. This device is basically a bridge rectifier. Efficiency is 98 percent.

The waste heat from this device must be rejected to space. A separate heat-pipe radiator is used. The evaporator is thermally attached to the appropriate electronics. The condenser is attached to a fin and radiates the waste heat to space. For the 400-kW_e NEP, this radiator is a right circular cylinder 0.6 m high and 4 m in diameter. During launch, this radiator is stored inside main radiator with the payload. After launch, the radiator and payload are deployed, allowing the closed cycle engines and thrusters to be activated.

2.3.8 Alternator Radiator

As shown in Figure 27, the alternator radiator must remove 20 kW_t. This radiator comprises the aft 2 m of the 3.2 m diameter cylindrical enclosure of the power system which is sufficient to maintain the alternator temperature at 390°K (240°F). Contact with ion engine designers indicates that there will be minimal interaction with ion beam and that thin graphite coatings ($\epsilon \cong 0.85$) will provide satis factory erosion resistance.

3.0 CONCLUSIONS

Current results clearly show that a nuclear electric spacecraft with a 400-kW_e reactor Brayton power system can be placed in orbit by a single Shuttle launch. The 400-kW_e reference system identified by this study employs a 1990 technology turbine inlet temperature of 1500°K (2240°F) using available refractory alloys and other conservative design parameters. Practical systems over the power range from 100 to 1000 kW_e have been identified with TITs from 1325 to 1650°K, and possibly 1800°K. Essentially current (1985) to projected (1995) technologies are represented, utilizing materials from superalloys to high-temperature refractory alloys and, ultimately, to ceramics. Use of a heat-pipe-cooled reactor, independent redundent power conversion loops, and heat-pipe radiators eliminates the single-point failure modes The specific mass performance parameter for the 400-kW_e power level is within 5 percent of the goal of 20 kg/kW_e which compares favorably with power systems based on other conversion means. Further refinement of the 400-kW_e system design with the new LASL layered core reactor, specifically tailored Brayton components, and more detailed design of the primary radiator based on new heat-pipe concepts will provide specific system masses below 20 kg/kW_e.

The heat-pipe cooled reactors now being defined by LASL utilize a relatively new concept that employs advanced technology. These reactors have great promise for broad applicability. Substantial research and technology work as well as subsequent development and testing are needed and should be strongly supported.

While closed Brayton cycle technology is receiving support because of its breadth of recognized applications, the special requirements for space service (e.g., performance parameters such as low specific mass, high efficiency, and reasonable specific radiator area; very high reliability with long life; and low comparative costs) need to be evaluated by parametric systems analysis and subsequent

research and technology work. Typical topics that need to be addressed include high-temperature materials, advanced heat exchangers, rotating machine elements including bearings, heat-pipe space radiator concepts, power processing elements, etc. Broad research and technology efforts in applicable types of advanced heat pipes are especially needed.

Future space missions are currently not well enough defined to permit proper focusing of technology and development efforts. More detailed optimizations of various classes of advanced missions are needed combining spaceflight trajectory analysis and parametric systems analysis with programmatic factors in the 1990 to 2010 time frame and beyond. This work is needed to help identify the kinds of technology that will be most useful and its timing.

Based on the study results, space power systems that use closed Brayton cycles may well find application in future nuclear electric spacecraft when definitive comparisons with other systems that include all pertinent factors are completed. Clearly, further work is needed to ascertain the degree and extent of the promise of CBC system vis-a-vis the competing power conversion systems.

4.0 RECOMMENDED FURTHER STUDIES AND ANALYSES

Based on results of the work accomplished in this study as well as previous efforts over many years on space power system development, the following recommendations are made for further studies and analyses of reactor Brayton power systems for nuclear electric spacecraft. In order to keep a technology viable, some continuity of effort is needed that keeps a minimum level of effort active. This is especially true at present when the new capabilities of the Space Shuttle transportation system are beginning to be understood and exploited. The Shuttle will have an increasing influence on the course of solar system exploration in the late 1980s, 1990s, and beyond, especially as the contribution of nuclear electric rocket propulsion is realized. Closed Brayton cycle power conversion, in both its established and advanced forms, has a role to play in the space power systems that are needed for solar system exploration, as well as a wide variety of other missions.

4.1 Refined System Designs, Including Reliability-Life Characteristics

The conceptual design of the 400-kW_e reference system should be refined to include LASL's new layered core reactors, specifically designed Brayton components, and detailed design of space radiators based on well-developed heat-pipe data. It may be desirable to investigate other specific power levels; for example, the currently identified 1200-kW_t LASL layered core reactor would provide between 250 and 350 kW_e using a Brayton power conversion system. In addition to determination of performance parameters in greater detail, it is timely to undertake the introduction of reliability and life factors in the analysis. The conversion of the present system design code into a parametric systems analysis code with modular elements should also be investigated.

4.2 Advanced Component Design

Current analytical techniques do not allow tailoring each Brayton component in detail for specific mission as well as system requirements. AiResearch recommends that the effect of novel heat transfer concepts, materials, configurations, and other requirements be investigated for the major Brayton components. A typical system design, such as the current 400-kW_e approach, would form the basis for this effort. Such important considerations as reliability, life, and cost need to be included as well as performance tradeoffs.

4.3 Space Radiator Designs with Advanced Heat Pipes

The primary heat rejection radiator is the dominant element in Brayton power systems for space applications. Special attention should be given to further conceptual design and analysis of space radiators with advanced heat pipes configured especially for this use. Many neoteric heat pipe designs, with wall materials and working fluids matched to the specific requirements of temperature, shape, meteoroid protection, and other pertinent requirements, should be evaluated.

4.4 System Operations and Safety

A study is recommended of the operational requirements of Brayton systems in space power service. The various operational phases such as system assembly, ground checkout, launch operations, orbital transfer, automated start-up, and power system regulation in space need to be studied and analyzed, especially with respect to their effect on overall system safety. Interactions of the Brayton components with the nuclear subsystem, spacecraft, and space transportation systems should be evaluated in, at least, an introductory manner. Preliminary outlines of the required system safety documents should be generated for interactive discussions with cognizant agencies.

4.5 Probability of Mission Success

The influence of the power system on the probability of mission success and the design and operational characteristics of the Brayton components are recommended for study in detail. This will require definition of typical missions in terms of mission goals and operational sequences. Since nuclear electric spacecraft will be used for complex missions throughout the solar system for durations of ten or more years, these reliability/availability studies are required to maximize the probability of performing a wide variety of missions successfully.

4.6 Economic Analyses Including Risks

Although non-recurring and recurring costs of Brayton power systems for space cannot be determined now with satisfactory accuracy (since only conceptual system designs and sketchy mission application information are available), it is not too soon to begin to develop the methodology for economic analysis. At the least, this will result in the necessary data being identified. Economic analyses of advanced systems, especially if they are to deal with risk, must be conducted on a probabilistic basis. Since it is necessary to keep such analyses as simple and clearly defined as possible, as appropriate to the available data and sophistication of the results, it is strongly recommended that the methodology for such analyses be formulated relatively early in the development program.

4.7 Space Shuttle Compatibility

An understanding of the Space Shuttle transportation system in some detail is necessary to be sure the Brayton-powered, nuclear electric spacecraft will be compatible with ground, launch, and space operations. Early attention to the detailed interfacing of the Brayton power system with the nuclear electric spacecraft and the Space Shuttle orbiter in all regimes is recommended.

5.0 RECOMMENDED TECHNOLOGY EFFORTS

In general, the closed Brayton power conversion system can be characterized as a mature technology ready for application (e.g., flight system development). The rather unusual operating conditions* required for the optimal systems defined in this study engenders a requirement for technology development in certain areas. Also, it must be recognized that there is currently very little supporting research or advanced technology either underway or being proposed which is aimed specifically at the requirements of space Brayton systems. Therefore, this section addresses these supporting technology needs and defines a preliminary schedule. This program would result in the required technology being demonstrated by target dates that are commensurate with current projections of flight system applications.

As summarized in Figure 30, a scenario of projected technology utilization for prospective flight applications has essentially been developed in Section 2.0 of this report. This figure indicates that the power requirements will increase exponentially with time. As described previously, a five-year flight system development and qualification program is assumed; therefore, technology readiness** needs to have been demonstrated five years before the proposed launch date.

*In terms of past space studies as well as more contemporary analyses of terrestrial power systems, the results of this study are characterized by lower efficiencies, higher ratios of CIT to TIT and lower recuperator effectivenesses to minimize the radiator mass and, thereby, the system mass.

**Technology readiness is that stage of system, subsystem, or component development where all major problems associated with achieving the specified on performance goals have been solved and where the solutions to problems have been successfully demonstrated through actual hardware design, fabrication, and test programs. At this stage, there remain no major risks for an agency or contractor in scaling up the technology (if full-scale demonstration has not been performed) and in proceeding with mission/commercial development of the system, subsystem, or component.

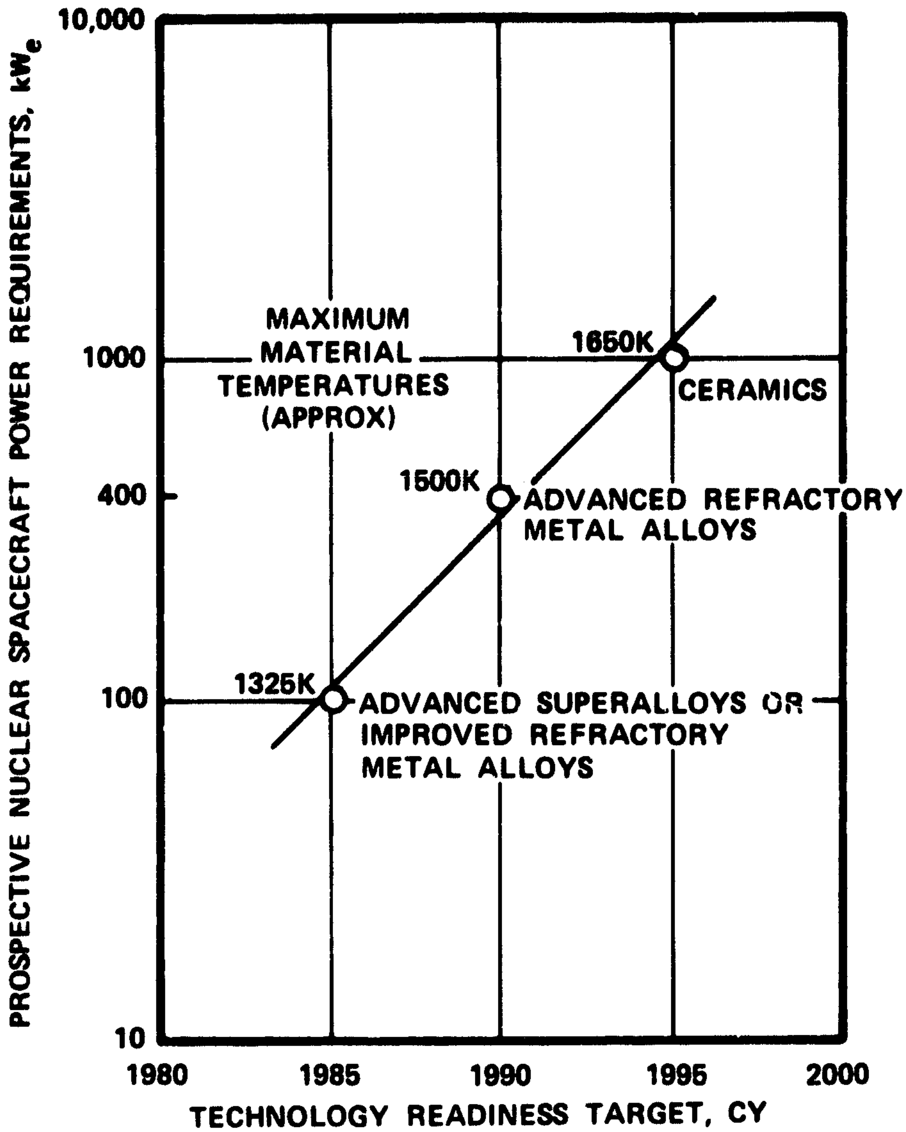

Figure 30. Prospective Nuclear Spacecraft Power Requirements Versus Technology Readiness.

Figure 30 shows three increasingly stringent levels of nuclear reactor powered system applications:

- o 100-kW_e power systems in the early 1990s
- o 400-kW_e power systems in the mid 1990s
- o 1000-kW_e power systems at the turn of the century

A schedule which lists the technology development areas required for increasingly sophisticated missions is shown in Figure 31, and discussed in some detail subsequently. It is important to note that approaches to the required technology can be defined at this time, e.g., no fundamentally new technology or "technical breakthrough" is required.

In projecting the technology requirements, the reactor heat source is not included. It was assumed that the current LASL development program will continue under independent sponsorship and that this program will yield the reactor technology as it becomes required.

5.1 100 kW_e System Technology

The current application forecast for this system is geocentric orbital power. Because of the large Shuttle lift capability for this class of missions, it is not necessary to achieve minimum system mass or volume to have a viable approach. This resulted in the choice of the 1325°K TIT, as noted previously.

The most necessary technology for this class of missions is in the area of materials. Current superalloys are limited to 1144 to 1172°K (1600 to 1650°F). Late developments in alloy modification using rapid solidification with powder metallurgy have currently resulted in allowable TIT increases of 56 to 83°K (100 to 150°F) with further improvement possible.

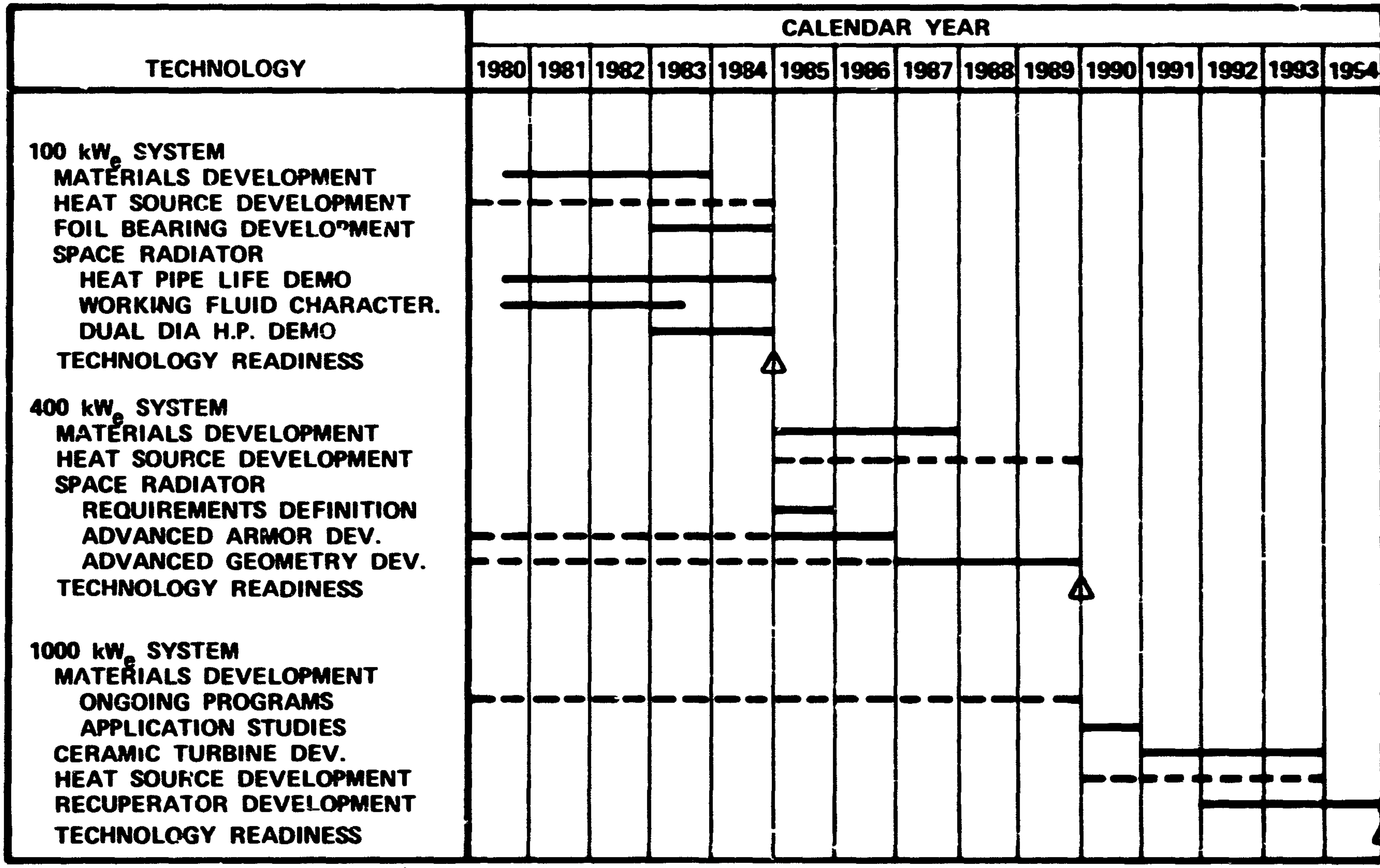

Figure 31. Schedule of Key Power Conversion Technology Elements Required for Reactor/Brayton Space Power Systems.

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The relatively well characterized refractory metals such as niobium have adequate stress carrying capabilities but questions regarding potential degradation due to even the low oxygen partial pressure which exists in near-Earth space must be resolved. For example, the durability of existing anti-oxidation coatings in the hard vacuum of space must be established.

A substantiated bank of standardized design data needs to be assembled, including definition of design nominals and minimums as well as an accepted methodology for life projection. Thus, a fairly comprehensive materials characterization effort will be required.

The reactor heat pipes are exposed to the highest temperatures in the closed loop and, as previously noted, will be made from refractory metals such as molybdenum or niobium. Methods of efficiently integrating these heat pipes into the heat source heat exchanger need to be studied, analytically and empirically. Potential approaches include an all-refractory metal design as well as one in which the heat exchanger wall could be made from metal, using internal insulation to limit hot spot exposure. In the latter case, either a thermally resilient seal between the refractory and superalloy or a weldment/brazement into a diaphragm-type thermal stress relief might be used.

In recent years, foil type gas bearings have come into increasingly wide-spread use in various commercial turbomachinery. For example, the bearings on the DC-10 air-conditioning air cycle units have accumulated over 53 X 10^6 bearing operating hours of operation and currently exhibit a mean time between bearing failure of 249,000 hours. Concurrently with these applications, dramatic strides advanced this technology from an empirical base to a discipline solidly supported by analysis and field operation. However, this analytical characterization effort has recently stagnated. To provide a proper technology base, this effort needs to be re-instituted to

establish a uniform methodology (including analytical, fabrication, inspection, and performance verification) for a variety of applications including space power systems. An important element is the development of a hydrodynamic/elastic computer model. The derivation and empirical verification of the predictions of such a model will be extremely significant in the avoidance and/or timely correction of problems during future applications.

The heat-pipe radiator for the 100-kW_e system (Figure 4) requires very little extension to existing technology. A ground-based, horizontal, extended life test of heat pipes using Dowtherm A and either mercury or rubidium working fluids should be instituted as early as practical to demonstrate that no unanticipated life-limiting mechanisms will be encountered. The data base for rubidium, especially, and mercury, to a certain extent, is insufficient for the heat-pipe designer's needs and should be expanded. The thermal decomposition or other life-limiting behavior of Dowtherm A should be investigated thoroughly as a function of temperature. To cut down the radiator mass, a statistically significant number of dual diameter (large evaporator, small condenser) heat pipes should be fabricated and subjected to thermal performance limit testing. Space testing of representative heat pipe designs should be undertaken at the earliest practical opportunity.

5.2 400-kW_e System Technology

Since the interplanetary spacecraft propulsion system uses the full Shuttle launch capability both in terms of injected mass and payload bay volume, power system performance is critical. Therefore, a higher TIT was selected for this system. In discussing the technology development implications for support of this system, it has been assumed that the items described in the preceding paragraph will have been completed, either in support of the 100-kW_e system development or under other program sponsorship in the intervening period.

The biggest payoff for the 400-kW_e system is in the area of heat-pipe space radiator technology development. A comprehensive effort should be completed to evolve the most realistic set of environmental design requirements, particularly in the definition of micrometeoroid flux levels. The variations in such exposure over the candidate missions should be defined so that the armor is designed realistically.

Armor geometries, materials, and manufacturing and application techniques should be investigated to minimize the penalty due this factor. The results of the current Thermacore study suggest that this topic has only recently begun to be pursued in the required depth. However, it may well have been completed prior to 1985, as the dashed line in Figure 31 indicates.

A concomitant effort on the investigation of the performance improvements possible by using advanced geometry heat pipes should also be completed, if not accomplished in the intervening years. Configuration-pumped and mechanically-pumped heat pipes are examples of the advanced types that need to be considered.

Additional materials development will be required to enable the 1500°K TIT (Figure 18) to be attained. Molybdenum and tantalum alloys are the leading candidates. The data base on these materials is sketchy and quite dated; thus, a significant effort in this area is indicated. Machinability, manufacturability, joining, and space environment tolerance under operating conditions are additional topics that will need to be addressed.

It will also be necessary to integrate the more advanced refractory materials into the heat source heat exchanger. It is believed that techniques which will have been developed for the 100-kW_e heat source will be applicable, but this needs to be confirmed.

5.3 1000-kW$_e$ System Technology

The projected missions and launch vehicles for this class of power systems are in the very early definition phase. Thus, it cannot be stated unequivocally that the higher performance selected for this system will absolutely be required. In the eventuality that lower performance is acceptable, the 1000-kW$_e$ missions could be accomplished by ganging three of the 400-kW$_e$ systems with a fourth as the redundant spare to yield an overall system with fairly respectable performance specifics.

However, it must be recognized that the historical trend in aerospace is to use the available technological capability to the fullest. Few rocket-powered vehicles have been launched that used only a fraction of their lifting capability, and there is little reason to suspect that this trend will change in the future (early projections regarding the usage of the space transportation system not withstanding). Therefore, this section will address technology development required to support the CBC systems operating at a TIT of 1650°K (2510°F) as listed in Figure 30.

In common with the systems described previously, the largest implication is on the materials needed for the high temperature components. As noted in Section 2.1.4 and indicated by the dashed line in Figure 31, the ceramic technology needed for this system is currently under active development for a number of programs. The differing requirements of the space power system will necessitate that a thorough analytical study, with possibly some supporting empirical effort, be undertaken to define how this technology may best be applied.

Following this effort, three fabrication/demonstration efforts associated with materials integration into critical components should be pursued. The ceramic turbine and associated static components

should be fabricated and assembled unless prior efforts have shown that components of the appropriate scale and materials have already been achieved. Most probably, ceramics will have to be used extensively in the reactor and ceramic heat pipes will be used between the reactor and heat source heat exchanger. The approach for providing extended surface on the condenser end in the heat source heat exchanger and the methods for sealing and integrating the heat pipes through the wall (ceramic or metallic) of the heat exchanger must be developed and demonstrated. Higher temperature capability materials are also needed for the recuperator. However, this should be within the range of the advanced refractories that will have been demonstrated at that point. Therefore, a fabrication/assembly technology demonstration program with these materials should be accomplished.

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APPENDIX A

PRELIMINARY LETTER REPORT #1
FROM
THERMACORE, INC.

(56 Pages)

THERMACORE, INC.

LEOLA, PENNSYLVANIA

April 1979

PRELIMINARY LETTER
REPORT
#1

CONTRACT 955437

METEOROID PROTECTION METHODS FOR SPACECRAFT RADIATORS USING HEAT PIPES

PREPARED FOR

CALIFORNIA INSTITUTE OF TECHNOLOGY
JET PROPULSION LABORATORY
PASADENA, CALIFORNIA

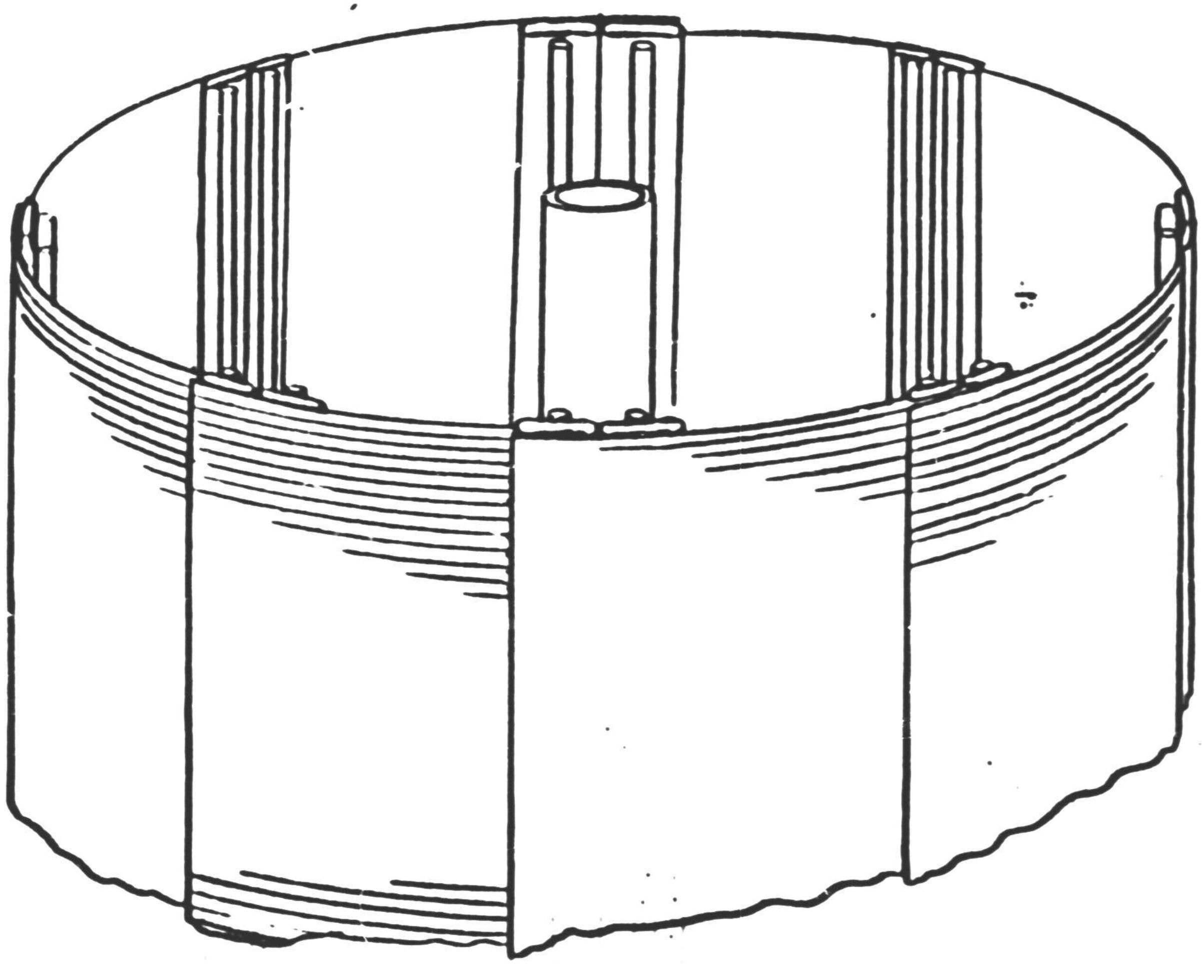
HEAT PIPE DESIGN FOR CBC RADIATOR

The 400 kW_e Closed Brayton Cycle power system for the Nuclear Electric Propulsion Spacecraft has been designed by Garrett AiResearch[2] to use heat pipes to achieve a thermally effective radiator which has a high survival probability. It is also anticipated that the heat pipe design will lead to a low specific mass. The heat pipe design evaluated in this work is for use in a cylindrical array as seen in Figure 3.1. This design has eight dual gas-to-radiator heat pipe heat exchangers fed from a dual central duct. The heat pipes are attached to both gas ducts over a length of 43 cm on each duct. Thus, the heat pipes provide armor protection for the gas ducts.

In normal operation, the total 86 cm length attachment over the heat pipes to the gas ducts will be used as heat pipe evaporators. The condenser is 176 cm long. If either gas duct or engine fail, then the whole power load will be transferred to the heat pipes through only one of the 43 cm attachments. Accordingly, for design consideratin, the heat pipe must be sized as though it had a 43 cm evaporator, 43 cm adiabatic and 176 cm condenser.

Four different sets of heat pipe designs were analyzed with respect to mass and performance. However, no consideration was given to the required heat pipe armor and tradeoffs in the heat pipe diameter versus T-bar fins for total mass. The overall heat pipe cell dimension as designed by GAR is 3.175 cm (1.25") and includes heat pipe and fins. All heat pipes discussed in the Sections 3.1 and 3.2 have computer printouts of their performance tabulated in Appendix 1.

FIGURE 3.1



CBC RADIATOR CONFIGURATION

3.1 Baseline Design

The total power to be dissipated is 1.1×10^6 watts. From the gas side of the radiator heat exchanger, heat pipe temperatures were calculated by Garrett AiResearch to range from 707°K down to 492°K. The power levels are 720 watts per heat pipe at 707°K and 169 watts per heat pipe at 492°K. Thus, $\sigma A \epsilon$ can be computed to be 2882×10^{-12} watts/°K^4 from:

$$P = \sigma A \epsilon T^4 \qquad \text{Equation 3.1}$$

where

P = power radiated - watts

σ = Stefan Boltzman Constant = $5.67 \times 10^{-12} \frac{\text{watts}}{\text{cm}^2\text{-}^{\circ}\text{K}^4}$

T = heat pipe temperature - °K

A = individual heat pipe radiating area - cm^2

ϵ = effective thermal emissivity

Table 3.1 shows the required heat pipe power for each of the end temperatures and each temperature divisible by 25°K.

Garrett AiResearch's baseline design is a 2.54 cm (1") O.D. heat pipe with a 0.0762 cm (.03") wall. The optimum heat pipe designs under these conditions are seen in Table 3.2. Rubidium is the preferred heat pipe fluid from 707°K down to 650°K. Below 650°K Dowtherm A (DTA) is the preferred fluid. In both cases, a screen covered groove design is found to be the lowest mass system. The rubidium heat pipes have a 1.75 Kg mass. The DTA heat pipes have a 1.74 Kg mass.

Table 3.3 shows the same heat pipes, which have been, for the most part, optimized with respect to the number of grooves and their aspect ratio. The rubidium heat pipes have a 1.48 Kg mass. The DTA heat pipes have a 1.55 Kg mass.

TABLE 3.1

Temperature		Req. Power
°K	°C	Watts
707	434	720
700	427	692
675	402	598
650	377	514
625	352	440
600	327	373
575	302	315
550	277	264
525	252	219
500	227	180
492	219	169

REQUIRED POWER PER HEAT PIPE AT ELEVEN DIFFERENT TEMPERATURES

TABLE 3.2

HEAT PIPE MASS & PERFORMANCE FOR BASELINE DESIGNS

Evaporator - 43 cm Adiabatic - 43 cm Condenser - 176 cm S = Sonic Limit C = Capillary Limit			Fluid: Rb O.D.: 2.54 cm # Grooves: 25	Vessel: 304 SS Wall: 0.0762 cm Groove Width: 0.2 cm			Fluid: DTA O.D.: 2.54 cm # Groove: 27	Vessel: 304 SS Wall: 0.0762 cm Groove Width: 0.2 cm		
Temperature		Req. Power	ΔT @ Req. Power	Power Limit	Mass	Groove Depth	ΔT @ Req. Power	Power Limit	Mass	Groove Depth
°K	°C	Watts	°C	Watts	Kg	Cm	°C	Watts	Kg	Cm
707	434	720	2.56	1750-S	1.75	0.05				
700	427	692								
675	402	598								
650	377	514	6.44	608-S	1.75	0.05				
625	352	440					3.89	545-C	1.74	0.065
600	327	373								
575	302	315								
550	277	264								
525	252	219								
500	227	180								
492	219	169					1.73	710-C	1.74	0.065

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TABLE 3.3

OPTIMIZED HEAT PIPE MASS & PERFORMANCE - BASELINE DESIGN

Evaporator - 43 cm
Adiabatic - 43 cm
Condenser - 176 cm
S = Sonic Limit
C = Capillary Limit

Rb: Fluid: Rb, Vessel: 304 SS, O.D.: 2.54 cm, Wall: 0.0762 cm, # Grooves: 25, Groove Width: 0.275 cm

DTA: Fluid: DTA, Vessel: 304 SS, O.D.: 2.54 cm, Wall: 0.0762 cm, # Groove: 25, Groove Width: 0.275 cm

Temperature		Req. Power	Rb: ΔT @ Req. Power	Rb: Power Limit	Rb: Mass	Rb: Groove Depth	DTA: ΔT @ Req. Power	DTA: Power Limit	DTA: Mass	DTA: Groove Depth
°K	°C	Watts	°C	Watts	Kg	Cm	°C	Watts	Kg	Cm
707	434	720	2.43	815-C	1.48	0.02				
700	427	692								
675	402	598								
650	377	514	5.83	640-S	1.48	0.02				
625	352	440					9.32	507-C	1.55	.055
600	327	373								
575	302	315								
550	277	264								
525	252	219								
500	227	180								
492	219	169					3.55	555-C	1.55	.055

The average mass reduction is 14%. Further optimization may result in an additional 1 or 2% mass reduction. However, far greater mass reduction can be realized by O.D. and/or wall thickness reduction.

Table 3.4 shows the 2.54 cm (1") heat pipe with a 0.025 cm (.01") wall. This wall thickness is 0.01 times the diameter and has been shown[7] to be acceptable for use as a heat pipe containment vessel where external buckling is the ultimate constraint, i.e., the internal pressure of the heat pipe was less than 14.7 psi, thus long term creep due to hoop stress was low.

The use of a wall thickness 0.01 times the diameter was developed for Niobium, which has a modulus of elasticity of 15 x 10^6 psi. This includes a safety factor of 2. Stainless steels have moduli of about 28 x 10^6 psi which reduces the thickness/diameter ratio to about 0.008 with a safety factor of 2. However, the use of 0.01 as a thickness to diameter ratio will be used to assure success.

Examination of DTA at 625°K shows a fluid pressure of 85 psi which develops a hoop stress of 4250 psi. This stress is acceptable, since 316 SS will only creep 0.1% in 10^5 hours at 1100°F under a stress of 6000 psi.

The rubidium heat pipes have a mass of 0.69 Kg and the DTA heat pipes have a mass of 0.78 Kg.

3.2 Design Optimization

Examination of Tables 3.2, 3.3 and 3.4 reveals that a reduction in diameter of the rubidium heat pipes would soon result in the heat pipe going sonic. However, the DTA pipes are capillary limited, thus a reduction in O.D. is possible. Accordingly, a higher pressure fluid, mercury,

TABLE 5.4

OPTIMIZED HEAT PIPE MASS & PERFORMANCE FOR THIN WALLED BASELINE DESIGN

Evaporator - 43 cm Adiabatic - 43 cm Condenser - 176 cm S = Sonic Limit C = Capillary Limit			Fluid: Rb O.D.: 2.54 cm # Grooves: 25		Vessel: 304 SS Wall: 0.0254 cm Groove Width: 0.275 cm		Fluid: DTA O.D.: 2.54 cm # Groove: 25		Vessel: 204 SS Wall: 0.0254 cm Groove Width: 0.275 cm	
Temperature		Req. Power	ΔT @ Req. Power	Power Limit	Mass	Groove Depth	ΔT @ Req. Power	Power Limit	Mass	Groove Depth
°K	°C	Watts	°C	Watts	Kg	Cm	°C	Watts	Kg	Cm
707	434	720	1.55	820-C	0.69	0.02				
700	427	692								
675	402	598								
650	377	514	4.56	705-C	0.69	0.02				
625	352	440					5.72	555-C	0.78	0.055
600	327	373								
575	302	315								
550	277	264								
525	252	219								
500	227	180								
492	219	169					2.49	710-C	0.78	0.055

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was used in small diameter pipes in place of rubidium. These results are seen in Table 3.5.

The mercury heat pipes are 0.635 cm (.250") in diameter with a wall to diameter ratio of 0.01. The mass of the mercury heat pipes are 0.45 Kg and have a hoop stress of 625 psi at 707°K.

The DTA heat pipes are 0.9525 cm (.37") in diameter with a wall to diameter ratio of 0.01. They have 12 grooves 0.275 cm wide by a depth that varies from 0.075 cm down to 0.05 cm. Accordingly, their mass varies from 0.31 Kg down to 0.27 Kg. The DTA heat pipes at 625°K will have a hoop stress of 1600 psi.

The mercury heat pipes of Table 3.5 have eight grooves 0.2 cm wide by 0.02 cm deep. Optimizing the number of 0.275 cm wide by .02 cm deep grooves for different power levels results in a reduction in mass. At 707°K, a five-groove heat pipe has a mass of 0.29 Kg. At 675°K, four grooves have a mass of 0.28 Kg and at 550°K, three grooves have a mass of 0.27 Kg. These results are seen in Table 3.6. Also shown in Table 3.6 is the thermal performance of two of the mercury heat pipes with 86 cm evaporators, which shows an increase in maximum power capability and a reduction in total ΔT.

Both the DTA heat pipes of Table 3.5 and the mercury heat pipes of Table 3.6 have a performance ΔT. Accordingly, one asks what does a ΔT in the heat pipe mean in increased mass (length of condenser) to be able to radiate the required power? Appendix 2 develops Equation 3.2 which is the increase in mass of heat pipe due to its ΔT.

$$dm = m \frac{l_c}{l_t}[(T_o/T)^4 - 1] \qquad \text{Equation 3.2}$$

TABLE 3.5

OPTIMIZED HEAT PIPE MASS & PERFORMANCE - ALTERNATE DESIGN

Evaporator - 43 cm Adiabatic - 43 cm Condenser - 176 cm S = Sonic Limit C = Capillary Limit			Fluid: Hg O.D.: 0.2952 cm # Grooves: 8 Vessel: 304 SS Wall: .01 cm Groove Width: 0.200 cm				Fluid: DTA O.D.: 1.27 cm # Groove: 12 Vessel: 304 SS Wall: 0.0127 cm Groove Width: 0.275 cm			
Temperature		Req. Power	ΔT @ Req. Power	Power Limit	Mass	Groove Depth	ΔT @ Req. Power	Power Limit	Mass	Groove Depth
°K	°C	Watts	°C	Watts	Kg	Cm	°C	Watts	Kg	Cm
707	434	720	2.69	930-S	0.45	0.02				
700	427	692								
675	402	598								
650	377	514								
625	352	440	1.98	900-C	0.45	0.02	15.04	515-C	0.31	0.075
600	327	373					10.73	420-C	0.29	0.065
575	302	315					8.38	370-C	0.29	0.06
550	277	264	2.08	805-C	0.45	0.02	6.49	305-C	0.28	0.055
525	252	219					4.98	240-C	0.27	0.05
500	227	180								
492	219	169					4.05	215-C	0.27	0.05

TABLE 6

OPTIMIZED HEAT PIPE MASS & PERFORMANCE – ALTERNATE DESIGN

Evaporator – 43 cm Adiabatic – 43 cm Condenser – 176 cm S = Sonic Limit C = Capillary Limit			Fluid: Hg O.D.: 0.635 cm # Grooves: 3-5		Vessel: 304 SS Wall: 0.00635 cm Groove Width: 0.2 cm		Fluid: Hg O.D.: 0.635 cm # Grooves: Evaporator: 86 cm Condenser: 176 cm		Vessel: 304 SS Wall: 0.00635 cm Groove Width: 0.2 cm	
Temperature		Req. Power	ΔT @ Req. Power	Power Limit	Mass	Groove Depth	ΔT @ Req. Power	Power Limit	Mass	Groove Depth
°K	°C	Watts	°C	Watts	Kg	Cm	°C	Watts	Kg	Cm
707	434	720	4.13	770–C	0.24	(5) .02	2.5	1625–C	0.29	(5) .02
700	427	692								
675	402	598	3.62	610–C	0.28	(4) .02				
650	377	514								
625	352	440	3.30	445–C	0.27	(3) .02				
600	327	373								
575	302	315								
550	277	264	8.35	350–C	0.27	(3) .02	4.79	560–S	0.27	(3) .02
525	252	219								
500	227	180								
432	219	169								

where dm = increase in mass

m = initial mass of heat pipe

l_c = length of heat pipe condenser

l_t = total length of heat pipes

T_o = desired operating temperature

T = actual operating temperature

$T_o - T$ = ΔT down heat pipe

From Table 3.5 and 3.6, using the lowest mass heat pipes, the increase in mass was calculated using Equation 3.2 and is tabulated in Table 3.7. Therefore, to a first approximation, one can say that the heat pipes for the CBC radiator will have a mass of 0.3 Kg each.

The performance of the mercury heat pipes is based on perfect wetting, that is, the wetting angle is zero (0). For long term stability, this may not be the case. Wetting angles from 0-60 degrees have been observed, with 30-60 degree angles, the most common. Since the capillary force is a function of the cosine of the wetting angle, the mercury heat pipes may have a reduction of capillary force of up to 50% (cos 60 = .5). This reduction in performance will then require a reoptimization of the heat pipes with a small increase in mass.

TABLE 3.7

INCREASE IN MASS DUE TO PERFORMANCE ΔT

TEMPERATURE (^oK)	POWER (W)	FLUID	MASS (Kg)	ΔT (^oC)	dM (Kg)	NEW MASS (Kg)
707	720	Hg	0.291	4.13	4.6×10^{-3}	0.296
700	692					
675	598	Hg	0.280	3.63	4.6×10^{-3}	0.284
650	514					
625	440	Hg	0.273	3.30	3.9×10^{-3}	0.277
600	373					
575	315	Hg	0.273	5.81	7.5×10^{-3}	0.280
550	264	DTA	0.280	6.49	1×10^{-2}	0.290
525	219	DTA	0.273	4.98	7.1×10^{-3}	0.280
500	180					
492	169	DTA	0.273	4.05	6.2×10^{-3}	0.279

3.3 Advanced Heat Pipe Concept

The groove heat pipe designs of Sections 3.1 and 3.2 optimized to an approximate mass of 0.3 Kg per heat pipe, exclusive of fins and armor. This mass is quite low and may be acceptable in the overall system. However, there are several heat pipe design concepts which may offer further reduced mass with increased performance. These include but are not limited to arterial wick heat pipes and configuration pumped heat pipes.

3.3.1. Artery/Wick Heat Pipes

There is a natural division in heat pipe fluids which takes place at approximately 600^{O}K. Above 600^{O}K, the liquid metals are useful working fluids. Below 600^{O}K, one generally deals with non-metallic fluids and devises structures which compensate for their inferior physical properties. The low temperature fluids, taken as a class, have relatively low latent heats of vaporization, low surface tension, and low thermal conductivity. The consequences are that for a given heat transfer rate, heat pipes using these fluids must move relatively large quantities of liquid with unusually low pressure losses, yet must maintain very thin liquid films in the heat flow path. The arterial wick structures of Figure 3.2 have been used to offset these property limitations. The artery provides the primary liquid return to the evaporator. This passage has a large hydraulic radius and provides a very low drag path. In the evaporator and condenser, a thin film of liquid is distributed circumferentially. The distribution wick is often a thin layer of screen or circumferential grooves.

The artery is removed from the evaporator and condenser heat flow paths. The thin films provided by the circumferential wick prevent the

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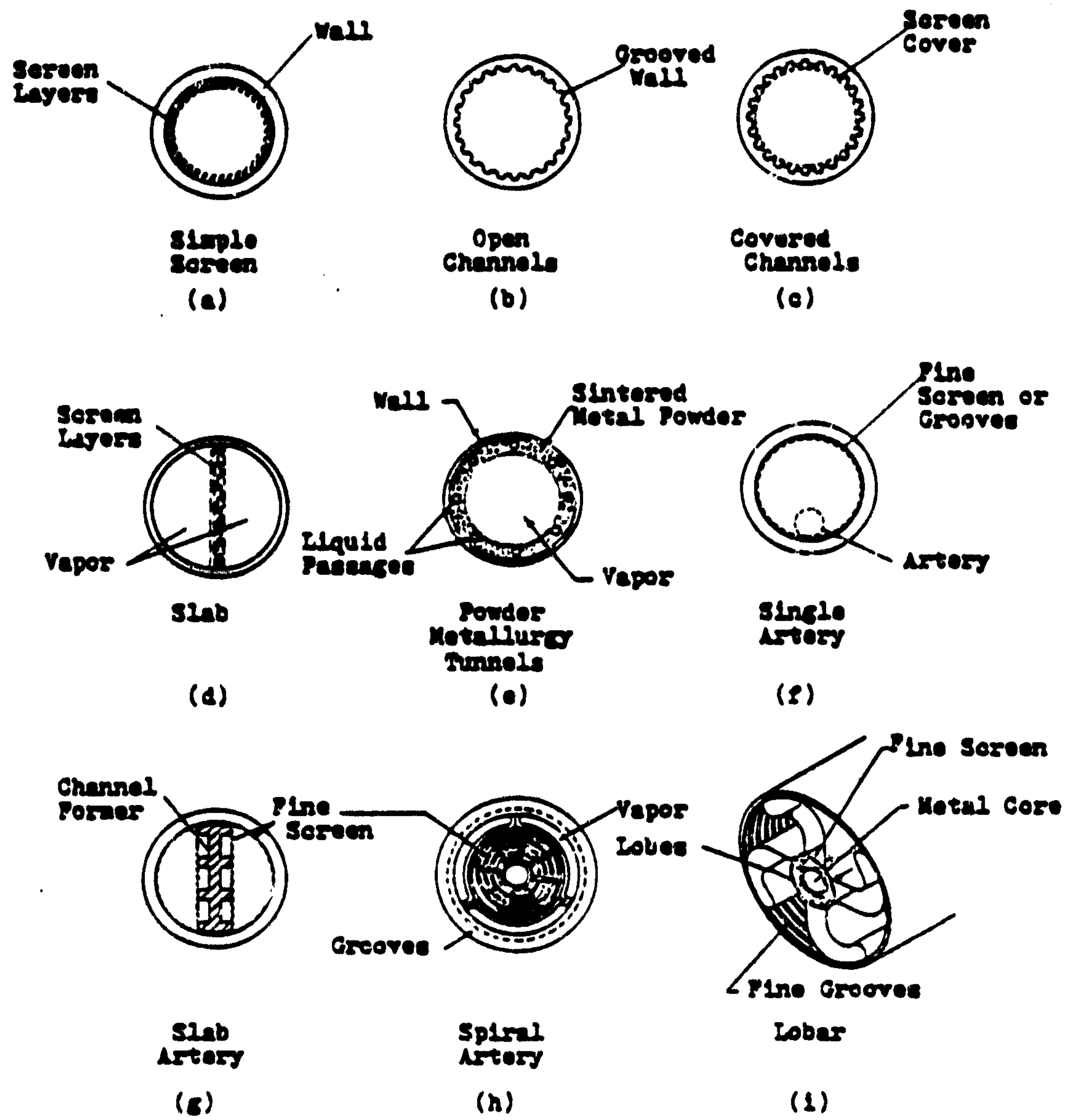

Figure 3.2 Representative Wick Geometries

development of excessive temperature gradients. Arterial wicks provide very high performance, sometimes even approaching that obtainable with liquid metals in more conventional wicks. Lengths in excess of ten meters have been reported. The primary limitations of arterial wicks lie in their difficulty of fabrication and their consequent lack of reproducible performance. The wick structures are quite difficult to form and to insert into the heat pipe vessel so as to maintain uniform close fit to the wall. There has been repeated difficulty with the priming of arteries, that is, the ability to fill an artery with fluid and keep it filled.

Two methods of priming are in use. Capillary priming, as the name implies, depends on capillary forces to maintain the fluid within the artery. The basic condition for capillary priming is that the largest single pore at the artery surface in the evaporator must provide sufficient capillary pressure to offset all counter forces including accelerations. Consequently, the evaporator ends of the arteries must be closed and there must be no single inadvertently large pore on the entire periphery of the enclosing surface. Due to the adverse effect of accelerations, capillary primed arteries can be more fractious during ground testing than in subsequent zero g operation. Yet ground testing is essential to establish the operability of the heat pipe.

If the artery is so located in the heat pipe temperature gradient that it always is the coldest spot, it will operate at a lower vapor pressure than the balance of the heat pipe. If the magnitude of the vapor pressure difference is sufficient, it will cause priming to take place. This is known as vapor pressure or Clapeyron priming. The process is highly temperature dependent. The pressure difference caused by a given temperature difference varies enormously with temperature. Thus, a heat pipe which primes reliably

and quickly at high temperature (i.e. high pressure) may fail to prime at all at low temperature. It has also been reported that vibration has caused arteries to l e their prime and that subsequent re-priming can be unreliable.

In spite of their apparent dra acks, the performance of arterial heat pipes is sufficiently high to justify further work to improve their reliability and reproducibility. In general, arterial wicks require less total mass of wicking material, and may also require less fluid inventory than conventional heat pipes. They are, therefore, serious candidates for use in space radiator.

3.3.2. Wickless (Configuration Pumped) Heat Pipes

A crevice has capillary properties. Therefore, if the wall of a non-round heat pipe is formed so as to produce longitudinal crevices, these may serve the purpose of wicks. That is, the configuration of the wall provides the capillary pumping force. Several potential configuration pumped heat pipe geometries are shown in Figure 3.3. Configuration pumped heat pipes have been built (Figure 3.4) and have been shown to operate. However, there has been very little work in the field, and the mathematical prediction of performance is incomplete.

The driving pressure difference which causes liquid flow in a heat pipe is determined by the surface tension and the difference in the radius of the liquid meniscus in the condenser and evaporator. Evaporation in the heat input section tends to depress the liquid level while condensation at the heat output end tends to increase the level. Thus, during operation, the liquid level in the evaporator of a configuration pumped heat pipe recedes into the crevice, increasing the pumping pressure but decreasing

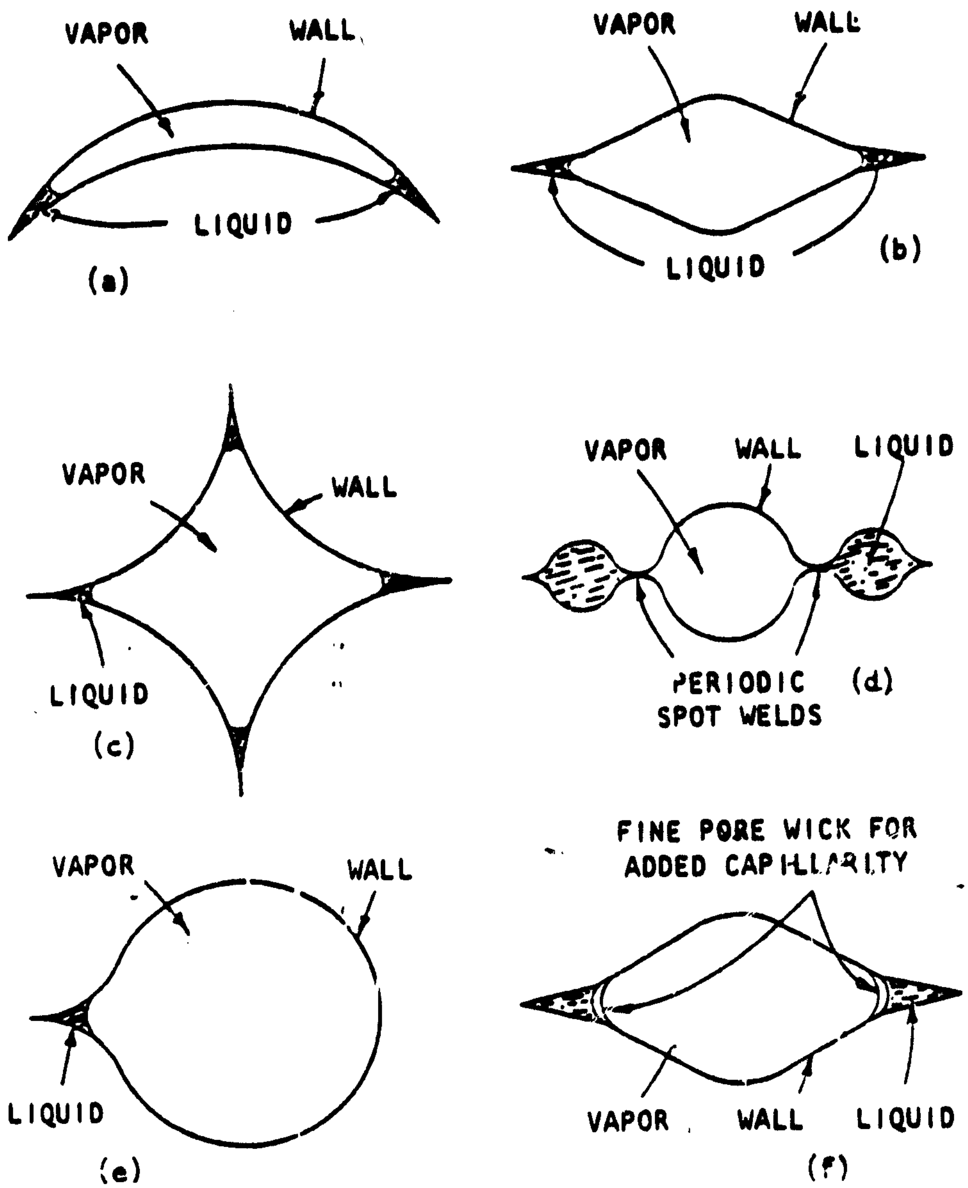

Figure 3.3 Configuration Pumped Geometries

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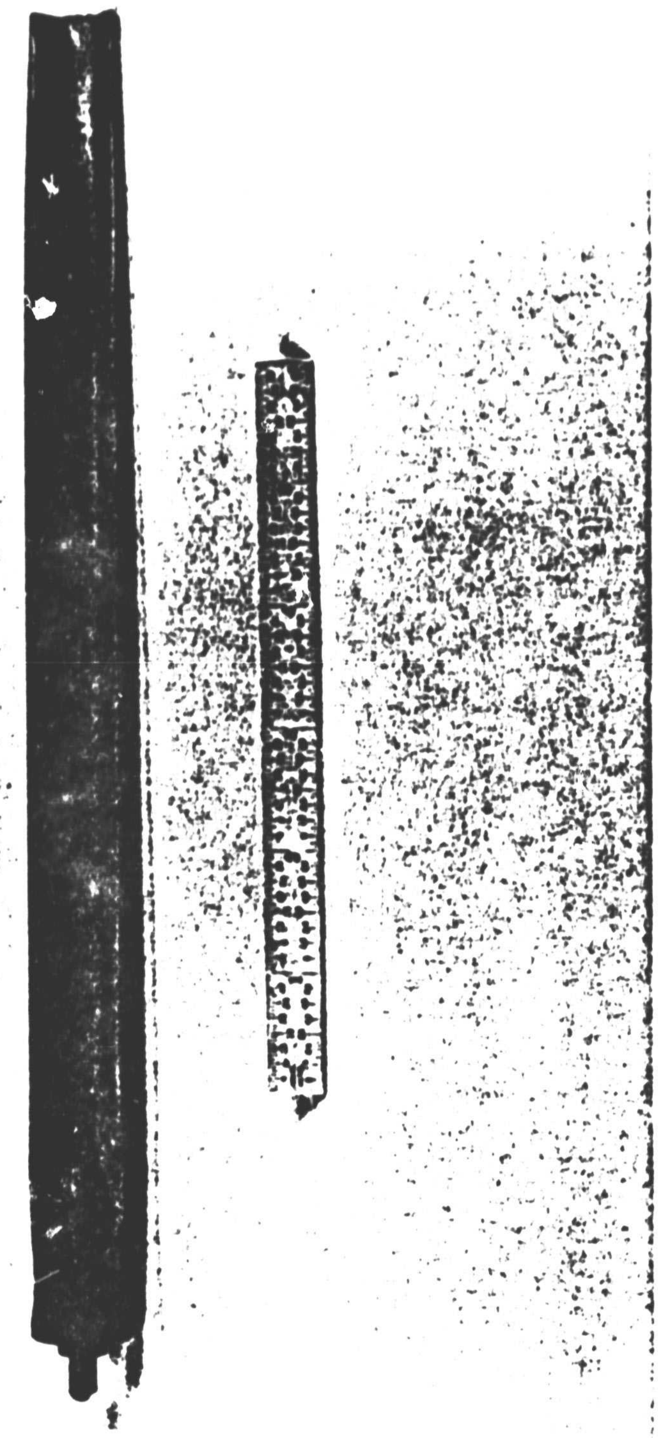


Photograph of a Configuration Pumped Heat Pipe
(Courtesy of U.S. Air Force)

FIGURE 3.4

the flow area. The inverse occurs in the condenser. This makes for a delicate tradeoff of liquid fill versus power handling capability. The problem is somewhat alleviated in the configuration/artery geometry of Figures 3.3d and 3.3f.

Configuration pumped heat pipes tend by their nature to have relatively low capillary pumping forces and low liquid drag. They therefore lend themselves well to consideration as elements in low temperature space radiators where large radiating areas require long heat pipes. The liquid inventory requirement of configuration pumped heat pipes appears to be comparable to that of the arterial structures discussed previously. The complete absence of conventional wicks is a substantial mass reduction. However, the non-round shapes are relatively poor pressure vessels so that the gain in mass due to elimination of the wick may be at least partially offset by a thicker wall requirement unless fluid vapor pressures are kept relatively low. Thus the operating temperature range for a configuration pumped heat pipe of low mass may be narrower than that for other geometries.

The ability of configuration pumped heat pipes to hold their shape is a function of the creep strength of the heat pipe envelope. Thermacore[2] previously identified the iron alloy, A-286, which exhibits an exceptionally high creep strength, and may well serve as a containment for configuration pumped heat pipes. (A-286 has a 0.1% creep at $1100^{\circ}F$ in 10^{5} hours under a 38,000 psi stress load).

3.3.3. Hybrid Wick/Pumped Heat Pipes

Since the dissipating capacity of a space radiator declines as the fourth power of any temperature loss, there is a strong incentive to minimize

losses. One of the principal advantages of the heat pipe is the low temperature loss it incurs while moving large amounts of heat. This low ΔT operation is characteristic of vapor heat transfer. There may, therefore, be reason to make use of vapor heat transfer even at power levels which cannot be sustained by capillary pumping alone. Alternative or hybrid pumping means are possible and deserve consideration. This may be true not only for the radiators themselves, but also for the primary loops feeding them. A practical hybrid system may use an alternative puming means for liquid transport over appreciable distances with capillary pumping for local distribution and collection.

The heat transfer capability of a conventional heat pipe can be limited by entrainment of liquid from the walls by the high velocity, counterflowing vapor. Seperation of the liquid and vapor passages will permit greater heat flow under these conditions. Figure 3.5 is a hybrid system where the liquid and vapor flow are in the same direction. Therefore, the vapor shear forces may aid rather than inhibit liquid flow.

Hybrid heat pipes are directly analagous to two-pipe steam heating systems for buildings which use condensate pumps for liquid return. The principle has been extended to liquid metals by Philips Laboratories for use in Stirling engines.

The main disadvanges of the hybrid system are the increased probability of a leak at pump seals and joints and the dependence of operation on an external power source. For maximum redundancy, there should be a pump for each heat pipe, a serious penalty in complexity for a space radiator, making the approach seem more applicable to primary loops.

It may be possible to make use of the "heat of the raidator" to pump the liquid, much the same way that a capillary pump makes use of the "heat

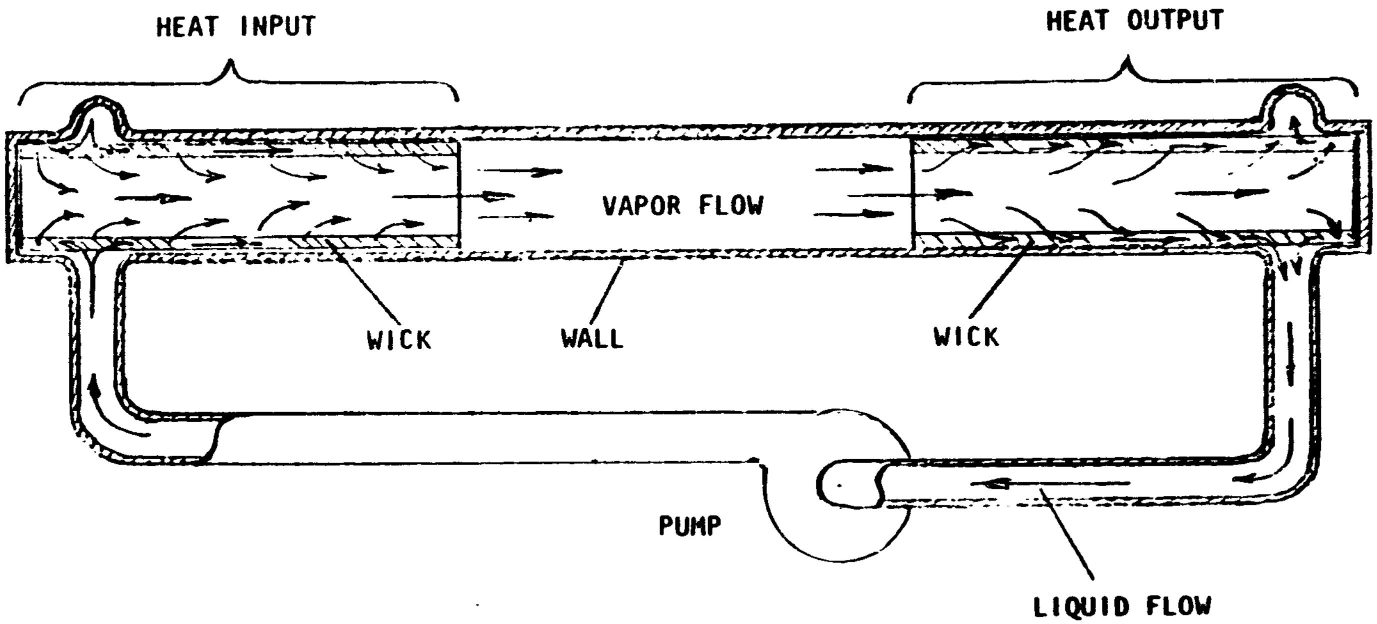


Figure 3.5 Mechanically Pumped Hybrid Heat Pipe

of the radiator."

Thermacore has recently begun the exploration of a "liquid piston pump" as part of its internal R&D effort. This pump uses a localized high heat flux, into the fluid, to develop a vapor bubble of sufficient pressure to push the liquid forward. Backward flow is prevented by the use of a check valve. A forward spring loaded valve allows the pressure at which the pump activates to be regulated.

Initial work to date has concentrated on gravity feed liquid systems with encouraging results. The extension of this concept to two phase systems with freedom from gravity will pose challenging work but may be worth a cursory investigation.

3.3.4. Other Concepts

There are numerous concepts which have been suggested as possible fluid pumping mechanisms for heat pipes and includes electro-magnetic, electrolytic, electrohydrodynamic and electrophoretic pumping. All of these are not suited for individual spacecraft radiator heat pipes. However, osmotic pumped heat pipes and artificial gravity are two possible mechanisms which are suited for spacecraft use.

If a spinning spacecraft can be so arranged that its centrifugal force will aid liquid return in heat pipes, it may be possible to eliminate pumping and depend entirely or predominantly on artificial gravity for this function. The result may be mass reduction (by wick elimination and, possibly, reduced fluid inventory) and an added degree of freedom in fluid selection (fluid need not have high surface tension).

Osmotic pressures can exceed capillary pressures by a factor of 100 to

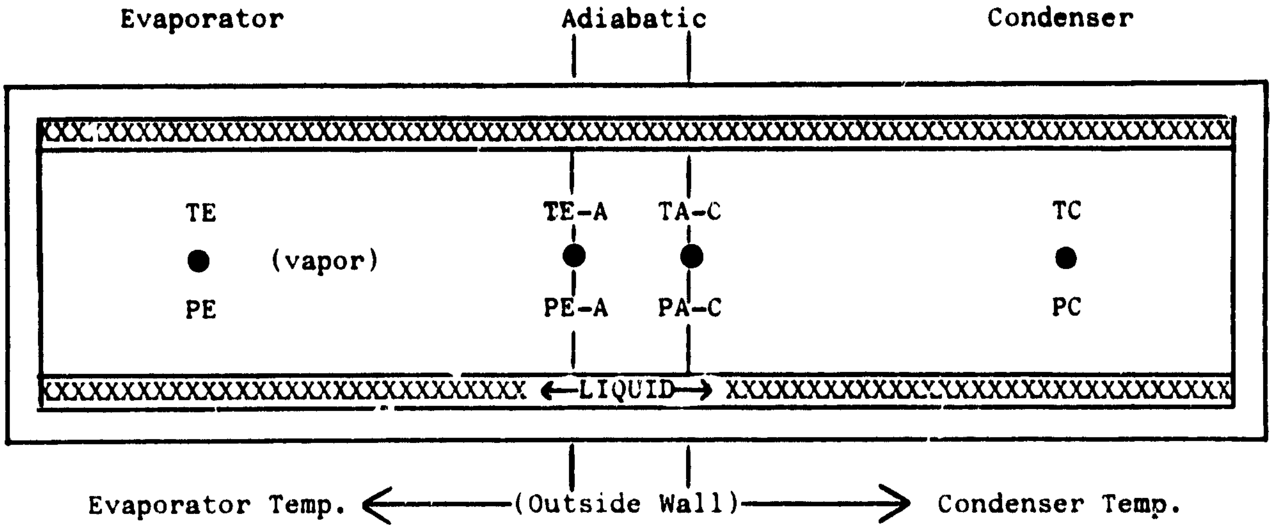
1,000. An osmotically pumped heat pipe is feasible in principle. Several designs have been proposed, but no hardware tests have been reported. The proposed designs all make use of gravity in one way or another: to keep liquid in place, to redistribute salt by natural convection, etc. It may be possible to devise a geometry which will function in gravity-free space. If so, osmotic heat pipes may avoid entirely the capillary limitations on available pumping pressure.

Flow rates through semi-permeable membranes are low; i.e., large areas are required to permit useful heat flow. There is, however, an interesting factor which may favor further consideration for low temperature space radiators. These radiators also require large areas because of the low radiant power densities. The osmotic process is such that the membrane must be located at the condenser (heat dissipating) end of the system, which is the radiating surface of a radiator. At temperatures below about $900^{\circ}K$, the power density from a black body radiator is less than the power density sustainable by flow of the best fluids (e.g. water) through membranes. That is, below this temperature the unit liquid flow rate through a membrane is more than sufficient to support the unit radiant heat load from a radiator of equal area, and a basic condition of successful operation has been satisfied.

The geometries considered to date are relatively massive, having two walls and a large liquid inventory. Membranes do not exist for operation above about $400^{\circ}K$. However, since an osmotic heat pipe would need no auxiliary power (comparable to a capillary heat pipe), it deserves further consideration.

APPENDIX 1

This appendix has complete performance printouts of all the heat pipes tabulated in Section 3.1 and 3.2. The heat pipe program used is Thermacore's GROOVE27. Figure A.1 depicts the placement and definitions of many of the symbols in the printout.



DPVE = Pressure drop in vapor in evaporator

DPLEG = Pressure drop in liquid in evaporator grooves

DPUA = Pressure drop in vapor in adiabatic

DPLAG = Pressure drop in liquid in adiabatic grooves

DPVC = Pressure drop in vapor in condenser - (+) means drop, (-) means recovery or increase

DPLGG = Pressure drop in liquid in condenser grooves

APPENDIX 2

This appendix develops Equation 3.2 which shows how the mass of a radiator heat pipe increases with the performance T of the heat pipe.

T_o = desired heat pipe temperature

ΔT = temperature drop down heat pipe

$T = T_o - \Delta T$, actual heat pipe radiating temperature

A_o = radiating area of heat pipe at T_o

$A = A_o + da$, actual heat pipe radiator area required at T

Q = power to be radiated from heat pipe

$$\frac{da}{dt} = \frac{\text{increase in surface area}}{\text{decrease in temperature}}$$

$$\frac{da}{dt} = \frac{A - A_o}{T_o - T} \qquad \text{Eq. A.1}$$

but $\quad A = \dfrac{Q}{\epsilon\sigma(T_o - T)^4} \quad$ and $\quad A_o = \dfrac{Q}{\epsilon\sigma T_o^{\,4}}$

therefore, with substitution into Equation A.1 and proper rearranging,

$$\frac{da}{dt} = \frac{A_o}{\Delta T}[(T_o/T)^4 - 1] \qquad \text{Eq. A.2}$$

Now, since area is a function of length, we have

$$dl = l_c[(T_o/T)^4 - 1] \qquad \text{Eq. A.3}$$

where l_c = condenser lenth, but $\dfrac{dl}{l_t} = \dfrac{dm}{m}$ where l_t = total heat pipe length, m = mass, we obtain with substitution and rearrangement -

$$dm = \frac{m l_c}{l_t}[T_o/T)^4 - 1] \qquad \text{Eq. A.4}$$

which is Equation 3.2.

REFERENCES

2. Garrett AiResearch, Study of a Space Nuclear Power System for a Nuclear Electric Spacecraft; JPL Contract 955008.

3. Thermacore, Inc., Letter Progress Report #3, October, 1978, Heat Pipe Heat Rejection System and Demonstration Model for the Nuclear Electric Propulsion (NEP) Spacecraft; JPL Contract 955100.

```
RUN CONDITIONS:                                    3:59 P.M.    4/ 5/79

FLUID = RUBIDIUM          WALL MATL=304SS
EVAP TEMP =  434          VAPOR DELTA-T =  50  DEG C
GRAV ANG =   0.00         WTG ANG =    0.00  DEG

EVAP  LENGTH   16.9291 IN   43.0000 CM
ADB   LENGTH   16.9291 IN   43.0000 CM
COND  LENGTH   69.2913 IN  176.0000 CM
TOTAL LENGTH  103.1500 IN  262.0000 CM

O.D.             1.0000 IN    2.5400 CM
WALL THKNSS      0.0300 IN    0.0762 CM
GROOVE WIDTH     0.0787 IN    0.2000 CM
GROOVE HEIGHT    0.0197 IN    0.0500 CM
LAND WIDTH       0.0344 IN    0.0875 CM
 25    GROOVES (CLOSED) COVERED WITH 200 MESH


NO LIMIT ENCOUNTERED AT ------------    720 WATTS

------------ TOTAL DELTA-T =    2.56  DEG C
------------ TOTAL MASS    =    1.749 KG

WANT PERFORMANCE DETAILS (Y OR N) ?Y

PE              PE-A            PA-C            PC              DYNES/CM2
 31291.9         30261.1         29954.9         30641.5

TE              TE-A            TA-C            TC              DEG C
 432.853         431.348         430.502         431.72

EVAP TEMP       COND TEMP       DELTA-T
 434             431.439         2.56104

DPC= 18214      DPG= 0      DPC+DPG= 18214  DYNES/CM2

DPVE            DPLED           DPVA            DPLAG
 1030            180             305             1115
DPVC            DPLCG
-687             739

SONIC LIMITS:         EVAP=   2197   ADB=   2487   WATTS

Q/A'S=          EVAP            COND            AXIAL           WATTS/CM2
                 2               0               142

E R REY#        E A REY#        LIQ REY#        C A REY#        C R REY#
 21              3244            109             3247            5

HOT FLUID CHARGE                           129.61    GRAMS
ROOM TEMP. VOLUME OF HOT FLUID CHARGE  84.6019    CM3

COLD FLUID CHARGE  151.635  GRAMS
                    98.9783  CM3

HEAT PIPE, (MESH) & 2 ENDCAPS  1596.9   GRAMS

DELTA-T VALUES:

EVAP WALL       EVAP LEG        EVAP MESH       EVAPORATION
 .328831         .120554E-01     .608936E-02     .300293         DEG C

VAPOR (E)       VAPOR (A)       VAPOR (C)
 1.3042          .545898        -1.21729

CONDENSATION    COND MESH       COND LEG        COND WALL
 .073387         .147544E-02     .292101E-02     .20283          DEG C


POWER OF   1775 WATTS CAUSES ------------ ADB  SONIC LIMIT

LAST NON-LIMITED POWER CALCULATION WAS AT ------------    1750 WATTS

------------ TOTAL DELTA-T =    7.16  DEG C
------------ TOTAL MASS    =    1.749 KG
```

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RUN CONDITIONS: 4:38 P.M.   3/22/79

FLUID = RUBIDIUM   WALL MATL=304SS
EVAP TEMP =   377   VAPOR DELTA-T = 50 DEG C
GRAV ANG =   0.00   VTD ANG =   0.00 DEG

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EVAP LENGTH	16.9291	IN	43.0000	CM
ADB LENGTH	16.9291	IN	43.0000	CM
COND LENGTH	69.2913	IN	176.0000	CM
TOTAL LENGTH	103.1500	IN	262.0000	CM

O.D.	1.0000	IN	2.5400	CM
WALL THICKSS	0.0300	IN	0.0762	CM
GROOVE WIDTH	0.0787	IN	0.2000	CM
GROOVE HEIGHT	0.0197	IN	0.0500	CM
LAND WIDTH	0.0344	IN	0.0876	CM

25   GROOVES (CLOSED) COVERED WITH 200 MESH

NO LIMIT ENCOUNTERED AT ----------   514 WATTS

---------- TOTAL DELTA-T =   6.44 DEG C
---------- TOTAL MASS   =   1.749 KG

WANT PERFORMANCE DETAILS (Y OR N) ?Y

PE	PE-A	PA-C	PC	DYNES/CM2
9905.91	8292.16	7774.8	8836.82	

TE	TE-A	TA-C	TC	DEG C
376.772	367.761	364.907	370.858	

EVAP TEMP	COND TEMP	DELTA-T
377	370.557	6.44312

DPC= 19141   DPG= 0   DPC+DPG= 19141 DYNES/CM2

DPVE	DPLED	DPVA	DPLAG
1613	132	517	821
DPVC	DPLCG		
-1113	543		

SONIC LIMITS: EVAP=   749   ADB=   703   WATTS

Q/A'S=	EVAP	COND	AXIAL	WATTS/CM2
	1	0	101	

E R REY#	E A REY#	LIQ REY#	C A REY#	C R REY#
16	2443	68	2456	3

HOT FLUID CHARGE   132.019   GRAMS
ROOM TEMP. VOLUME OF HOT FLUID CHARGE 86.1741   CM3

COLD FLUID CHARGE 151.636 GRAMS
                    98.9783 CM3

HEAT PIPE, (MESH) & 2 ENDCAPS 1596.9   GRAMS

DELTA-T VALUES:

EVAP WALL	EVAP LQG	EVAP MESH	EVAPORATION	
.316904	.712316E-02	.353976E-02	.600536	DEG C

VAPOR (E)	VAPOR (A)	VAPOR (C)
3.01123	2.85352	-5.9502

CONDENSATION	COND MESH	COND LQG	COND WALL	
.146734	.862923E-03	.170859E-02	.151184	DEG C

POWER OF   609 WATTS CAUSES ---------- ADB SONIC LIMIT

LAST NON-LIMITED POWER CALCULATION WAS AT ----------   608 WATTS

---------- TOTAL DELTA-T =   7.34 DEG C
---------- TOTAL MASS   =   1.749 KG

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RUN CONDITIONS:                                 4:18 P.M.    3/22/79

FLUID = DOWTHERM A        WALL MATL=304SS
EVAP TEMP =  352          VAPOR DELTA-T =  50  DEG C
GRAV ANG =    0.00        WTS ANG =    0.00  DEG

EVAP  LENGTH    16.9291 IN    43.0000 CM
ADB   LENGTH    16.9291 IN    43.0000 CM
COND  LENGTH    69.2913 IN   176.0000 CM
TOTAL LENGTH   103.1500 IN   262.0000 CM

O.D.             1.0000 IN     2.5400 CM
WALL THKNSS      0.0300 IN     0.0762 CM
GROOVE WIDTH     0.0787 IN     0.2000 CM
GROOVE HEIGHT    0.0256 IN     0.0650 CM
LAND WIDTH       0.0247 IN     0.0627 CM
 27    GROOVES (CLOSED) COVERED WITH 200 MESH


NO LIMIT ENCOUNTERED AT -----------      440 WATTS

----------- TOTAL DELTA-T =     3.89  DEG C
----------- TOTAL MASS    =     1.744 KG

WANT PERFORMANCE DETAILS (Y OR N) ?Y

PE              PE-A            PA-C            PC              DYNES/CM2
 .546112E+07     .546109E+07     .546106E+07     .546105E+07

TE              TE-A            TA-C            TC              DEG C
 348.876         348.876         348.875         348.875

EVAP TEMP       COND TEMP       DELTA-T
 352             348.11          3.88989

DPC= 3160       DPG= 0      DPC+DPG= 3160    DYNES/CM2

DPVE            DPLE            DPVA            DPLA
 19              233             7               1339
DPVC            DPLC
 8               956

SONIC LIMITS:         EVAP= 156526   ADB= 188977   WATTS

Q/A'S=          EVAP            COND            AXIAL           WATTS/CM2
                 1               0               86

E R REY#        E A REY#        LIQ REY#        C A REY#        C R REY#
 5               305             346             305             1

HOT FLUID CHARGE                          114.957   GRAMS
ROOM TEMP. VOLUME OF HOT FLUID CHARGE     107.637   CM3

COLD FLUID CHARGE  133.501  GRAMS
                   125.001  CM3

HEAT PIPE, (MESH) & 2 ENDCAPS  1610.42  GRAMS

DELTA-T VALUES:

EVAP WALL       EVAP LIQ        EVAP MESH       EVAPORATION
 .535963         1.34221         .64413          .100098         DEG C

VAPOR (E)       VAPOR (A)       VAPOR (C)
 .488281E-03     .488281E-03     .244141E-03

CONDENSATION    COND MESH       COND LIQ        COND WALL
 .244557E-01     .187453         .450962         .131558         DEG C


POWER OF     550 WATTS CAUSES ----------- CAPILLARY LIMIT, DPL > DPV

LAST NON-LIMITED POWER CALCULATION WAS AT -----------     545 WATTS

----------- TOTAL DELTA-T =     4.79  DEG C
----------- TOTAL MASS    =     1.744 KG
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RUN CONDITIONS: 8:41 A.M.   3/23/79

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FLUID = DOWTHERM A   WALL MATL=304SS
EVAP TEMP = 219   VAPOR DELTA-T = 50 DEG C
GRAV ANG = 0.00   ATO ANG = 0.00 DEG

EVAP LENGTH	16.9291	IN	43.0000	CM
ADB LENGTH	16.9291	IN	43.0000	CM
COND LENGTH	69.2913	IN	176.0000	CM
TOTAL LENGTH	103.1500	IN	262.0000	CM

O.D.	1.0000	IN	2.5400	CM
WALL THKNSS	0.0300	IN	0.0762	CM
GROOVE WIDTH	0.0787	IN	0.2000	CM
GROOVE HEIGHT	0.0256	IN	0.0650	CM
LAND WIDTH	0.0247	IN	0.0627	CM

27 GROOVES (CLOSED) COVERED WITH 200 MESH

NO LIMIT ENCOUNTERED AT ------------ 160 WATTS

------------ TOTAL DELTA-T = 1.73 DEG C
------------ TOTAL MASS = 1.744 KG

WANT PERFORMANCE DETAILS (Y OR N) ?Y

PE	PE-A	PA-C	PC	DYNES/CM2
402517	402492	402462	402432	

TE	TE-A	TA-C	TC	DEG C
217.618	217.615	217.612	217.609	

EVAP TEMP	COND TEMP	DELTA-T
219	217.271	1.72906

DPC= 7261   DPG= 0   DPC+DPG= 7261   DYNES/CM2

DPVE	DPLED	DPVA	DPLAG
24	181	21	868
DPVC	DPLCG		
29	619		

SONIC LIMITS: EVAP= 15075   ADB= 17120   WATTS

Q/A'S=	EVAP	COND	AXIAL	WATTS/CM2
	0	0	33	

E R REY#	E A REY#	LIQ REY#	C A REY#	C R REY#
2	325	42	325	0

HOT FLUID CHARGE   112.977   GRAMS
ROOM TEMP. VOLUME OF HOT FLUID CHARGE   105.784   CM3

COLD FLUID CHARGE 133.501 GRAMS
                  125.001 CM3

HEAT PIPE, (MESH) & 2 ENDCAPS 1610.42 GRAMS

DELTA-T VALUES:

EVAP WALL	EVAP L&G	EVAP MESH	EVAPORATION	
.228554	.780453	.272907	.100098	DEG C

VAPOR (E)	VAPOR (A)	VAPOR (C)
.32196E-02	.292969E-02	.292969E-02

CONDENSATION	COND MESH	COND L&G	COND WALL	
.244657E-01	.666962E-01	.190864	.055916	DEG C

POWER OF 715 WATTS CAUSES ------------ CAPILLARY LIMIT, DPL > DPV

LAST NON-LIMITED POWER CALCULATION WAS AT ------------ 710 WATTS

------------ TOTAL DELTA-T = 6.37 DEG C
------------ TOTAL MASS = 1.744 KG

RUN CONDITIONS: 10:07 A.M.   3/28/79

FLUID = RUBIDIUM   WALL MATL=304SS
EVAP TEMP = 434   VAPOR DELTA-T = 80 DEG C
GRAV ANG = 0.00   VTO ANG = 0.00 DEG

EVAP LENGTH	16.9291 IN	43.0000 CM
ADB LENGTH	16.9291 IN	43.0000 CM
COND LENGTH	69.2913 IN	176.0000 CM
TOTAL LENGTH	103.1500 IN	262.0000 CM

O.D.	1.0000 IN	2.5400 CM
WALL THKNSS	0.0300 IN	0.0762 CM
GROOVE WIDTH	0.1083 IN	0.2750 CM
GROOVE HEIGHT	0.0079 IN	0.0200 CM
LAND WIDTH	0.0079 IN	0.0200 CM

28 GROOVES (CLOSED) COVERED WITH 200 MESH

NO LIMIT ENCOUNTERED AT ------------ 720 WATTS

------------ TOTAL DELTA-T = 2.43 DEG C
------------ TOTAL MASS = 1.484 KG

WANT PERFORMANCE DETAILS (Y OR N) ??

PE	PE-A	PA-C	PC	DYNES/CM2
31296.8	30370.4	30100.3	30718.1	

TE	TE-A	TA-C	TC	DEG C
432.861	431.242	430.762	431.849	

EVAP TEMP	COND TEMP	DELTA-T
434	431.57	2.42993

DPC= 18214   DPG= 0   DPC+DPG= 18214 DYNES/CM2

DPVE	DPLE	DPVA	DPLAG
926	1196	269	9336
DPVC	DPLCG		
-615	4900		

SONIC LIMITS: EVAP= 23.4   ADB= 2631   WATTS

Q/A'S=	EVAP	COND	AXIAL	WATTS/CM2
	2	0	142	

E R REY#	E A REY#	LIQ REY#	C A REY#	C R REY#
21	3161	92	3163	6

HOT FLUID CHARGE   92.1796 GRAMS
ROOM TEMP. VOLUME OF HOT FLUID CHARGE 60.1694 CM3

COLD FLUID CHARGE 107.824 GRAMS
                    70.3814 CM3

HEAT PIPE, (MESH) & 2 ENDCAPS 1375.82 GRAMS

DELTA-T VALUES:

EVAP WALL	EVAP L&G	EVAP MESH	EVAPORATION	
.828831	.352[illegible]E-02	.593373E-02	.300293	DEG C

VAPOR (E)	VAPOR (A)	VAPOR (C)
1.61914	.479736	-1.08667

CONDENSATION	COND MESH	COND L&G	COND WALL	
.073367	.143844E-02	.354731E-03	.202311	DEG C

POWER OF 820 WATTS CAUSES ------------ CAPILLARY LIMIT, DPL > DPV

LAST NON-LIMITED POWER CALCULATION WAS AT ------------ 816 WATTS

------------ TOTAL DELTA-T = 2.87 DEG C
------------ TOTAL MASS = 1.484 KG

FLUID = RUBIDIUM WALL MATL=304SS
EVAP TEMP = 377 VAPOR DELTA-T = 50 DEG C
GRAV ANG = 0.00 WTG ANG = 0.00 DEG

EVAP LENGTH	16.9291	IN	43.0000	CM
ADB LENGTH	16.9291	IN	43.0000	CM
COND LENGTH	69.2913	IN	176.0000	CM
TOTAL LENGTH	103.1500	IN	262.0000	CM

O.D.	1.0000	IN	2.5400	CM
WALL THKNSS	0.0300	IN	0.0762	CM
GROOVE WIDTH	0.1083	IN	0.2750	CM
GROOVE HEIG'	0.0079	IN	0.0200	CM
LAND WIDTH	0.0079	IN	0.0200	CM

25 GROOVES (CLOSED) COVERED WITH 200 MESH

NO LIMIT ENCOUNTERED AT ------------ 814 WATTS

------------ TOTAL DELTA-T = 5.83 DEG C
------------ TOTAL MASS = 1.484 KG

WANT PERFORMANCE DETAILS (Y OR N) ?Y

PE	PE-A	PA-C	PC	DYNES/CM2
9928.78	8499.64	8051.89	9003.7	

TE	TE-A	TA-C	TC	DEG C
375.877	368.863	366.456	371.445	

EVAP TEMP	COND TEMP	DELTA-T
377	371.17	5.82983

DPC= 19139 DPG= 0 DPC+DPG= 19139 DYNES/CM2

DPVE	DPLEG	DPVA	DPLAG
1429	877	447	6867
DPVC	DPLCG		
-952	3599		

SONIC LIMITS: EVAP= 790 ADB= 765 WATTS

Q/A'S=	EVAP	COND	AXIAL	WATTS/CM2
	1	0	101	

E R REY#	E A REY#	LIQ REY#	C A REY#	C R REY#
16	2381	58	2392	3

HOT FLUID CHARGE 93.8783 GRAMS
ROOM TEMP. VOLUME OF HOT FLUID CHARGE 61.2782 CM3

COLD FLUID CHARGE 107.824 GRAMS
70.3814 CM3

HEAT PIPE, (MESH) & 2 ENDCAPS 1375.82 GRAMS

DELTA-T VALUES:

EVAP WALL	EVAP L&G	EVAP MESH	EVAPORATION	
.615994	.203109E-02	.350565E-02	.500488	DEG C

VAPOR (E)	VAPOR (A)	VAPOR (C)
7.01489	2.40698	-4.9895

CONDENSATION	COND MESH	COND L&G	COND WALL	
.122278	.842339E-03	.500006E-03	.151117	DEG C

POWER OF 845 WATTS CAUSES ------------ ADB SONIC LIMIT

LAST NON-LIMITED POWER CALCULATION WAS AT ------------ 840 WATTS

------------ TOTAL DELTA-T = 7.13 DEG C
------------ TOTAL MASS = 1.484 KG

RUN CONDITIONS: 12: 2 P.M. 3/28/79 7

FLUID = DOWTHERM A WALL MATL=304SS
EVAP TEMP = 352 VAPOR DELTA-T = 50 DEG C
GRAV ANG = 0.00 WTG ANG = 0.00 DEG

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EVAP LENGTH	16.9291 IN	43.0000 CM
ADB LENGTH	16.9291 IN	43.0000 CM
COND LENGTH	69.2913 IN	176.0000 CM
TOTAL LENGTH	103.1500 IN	262.0000 CM

O.D.	1.0000 IN	2.5400 CM
WALL THKNSS	0.0300 IN	0.0762 CM
GROOVE WIDTH	0.1083 IN	0.2750 CM
GROOVE HEIGHT	0.0217 IN	0.0550 CM
LAND WIDTH	0.0044 IN	0.0112 CM

25 GROOVES (CLOSED) COVERED WITH 200 MESH

NO LIMIT ENCOUNTERED AT ----------- 440 WATTS

----------- TOTAL DELTA-T = 9.23 DEG C
----------- TOTAL MASS = 1.548 KG

WANT PERFORMANCE DETAILS (Y OR N) ?Y

PE	PE-A	PA-C	PC	DYNES/CM2
.511061E+07	.511059E+07	.511058E+07	.511054E+07	

TE	TE-A	TA-C	TC	DEG C
344.891	344.391	344.891	344.89	

EVAP TEMP	COND TEMP	DELTA-T
352	342.773	9.22729

DPC= 3294 DPG= 0 DPC+DPG= 3294 DYNES/CM2

DPVE	DPLEG	DPVA	DPLAG
18	219	7	1430
DPVC	DPLCG		
7	896		

SONIC LIMITS: EVAP= 150576 ADB= 181288 WATTS

Q/A'S=	EVAP	COND	AXIAL	WATTS/CM2
	1	0	86	

E R REY#	E A REY#	LIQ REY#	C A REY#	C R REY#
5	797	291	797	1

HOT FLUID CHARGE 120.205 GRAMS
ROOM TEMP. VOLUME OF HOT FLUID CHARGE 112.551 CM3

COLD FLUID CHARGE 141.404 GRAMS
132.401 CM3

HEAT PIPE, (MESH) & 2 ENDCAPS 1406.22 GRAMS

DELTA-T VALUES:

EVAP WALL	EVAP LEG	EVAP MESH	EVAPORATION	
.536983	6.13104	.640463	.100098	DEG C

VAPOR (E)	VAPOR (A)	VAPOR (C)
.244141E-03	.244141E-03	.244141E-03

CONDENSATION	COND MESH	COND LEG	COND WALL	
.244557E-01	.156617	1.50406	.132076	DEG C

POWER OF 575 WATTS CAUSES ----------- CAPILLARY LIMIT, DPL > DPV

LAST NON-LIMITED POWER CALCULATION WAS AT ----------- 570 WATTS

----------- TOTAL DELTA-T = 11.92 DEG C
----------- TOTAL MASS = 1.548 KG

RUN CONDITIONS: 11:50 A.M.   3/28/79

FLUID = DOWTHERM A   WALL MATL=304SS
EVAP TEMP = 219   VAPOR DELTA-T = 50 DEG C
GRAV ANG = 0.00   WTD ANG = 0.00 DEG

EVAP LENGTH	16.9291	IN	43.0000	CM
ADB LENGTH	16.9291	IN	43.0000	CM
COND LENGTH	69.2913	IN	176.0000	CM
TOTAL LENGTH	103.1500	IN	262.0000	CM

O.D.	1.0000	IN	2.5400	CM
WALL THKNSS	0.0300	IN	0.0762	CM
GROOVE WIDTH	0.1083	IN	0.2750	CM
GROOVE HEIGHT	0.0197	IN	0.0500	CM
LAND WIDTH	0.0049	IN	0.0125	CM

25 GROOVES (CLOSED) COVERED WITH 200 MESH

NO LIMIT ENCOUNTERED AT ----------- 169 WATTS

------------ TOTAL DELTA-T = 3.56 DEG C
------------ TOTAL MASS = 1.535 KG

WANT PERFORMANCE DETAILS (Y OR N) ?Y

PE	PE-A	PA-C	PC	DYNES/CM2
387562	387538	387503	387479	

TE	TE-A	TA-C	TC	DEG C
216.152	216.149	216.146	216.143	

EVAP TEMP	COND TEMP	DELTA-T
219	215.446	3.55353

DPC= 7307   DPG= 0   DPC+DPG= 7307   DYNES/CM2

DPVE	DPLEG	DPVA	DPLAG
24	179	20	1200
DPVC	DPLCG		
29	736		

SONIC LIMITS: EVAP= 14943   ADB= 16962   WATTS

Q/A'S=	EVAP	COND	AXIAL	WATTS/CM2
	0	0	33	

E R REY#	E A REY#	LIQ REY#	C A REY#	C R REY#
2	321	36	321	0

HOT FLUID CHARGE   111.829   GRAMS
ROOM TEMP. VOLUME OF HOT FLUID CHARGE   104.709   CM3

COLD FLUID CHARGE   131.942 GRAMS
                    123.541 CM3

HEAT PIPE, (MESH) & 2 ENDCAPS 1402.85 GRAMS

DELTA-T VALUES:

EVAP WALL	EVAP L&G	EVAP MESH	EVAPORATION	
.228554	2.24923	.269845	.100098	DEG C

VAPOR (E)	VAPOR (A)	VAPOR (C)
.322064E-02	.292969E-02	.292969E-02

CONDENSATION	COND MESH	COND L&G	COND WALL	
.244557E-01	.688972E-01	.550474	.559992E-01	DEG C

POWER OF 559 WATTS CAUSES ------------ CAPILLARY LIMIT, DPL > DPV

LAST NON-LIMITED POWER CALCULATION WAS AT ------------ 553 WATTS

------------ TOTAL DELTA-T = 11.48 DEG C
------------ TOTAL MASS = 1.535 KG

RUN CONDITIONS: 4: 7 P.M.   4/ 5/79

FLUID = RUBIDIUM   WALL MATL=304SS
EVAP TEMP = 434   VAPOR DELTA-T = 50 DEG C
GRAV ANG = 0.00   VTG ANG = 0.00 DEG

EVAP LENGTH	16.9291	IN	43.0000	CM
ADB LENGTH	16.9291	IN	43.0000	CM
COND LENGTH	69.2913	IN	176.0000	CM
TOTAL LENGTH	103.1500	IN	262.0000	CM

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O.D.	1.0000	IN	2.5400	CM
WALL THKNSS	0.0300	IN	0.0762	CM
GROOVE WIDTH	0.1083	IN	0.2750	CM
GROOVE HEIGHT	0.0079	IN	0.0200	CM
LAND WIDTH	0.0079	IN	0.0200	CM

25 GROOVES (CLOSED) COVERED WITH 200 MESH

NO LIMIT ENCOUNTERED AT ------------ 720 WATTS

------------ TOTAL DELTA-T = 2.43 DEG C
------------ TOTAL MASS = 1.484 KG

WANT PERFORMANCE DETAILS (Y OR N) ?Y

PE	PE-A	PA-C	PC	DYNES/CM2
31296.8	30370.4	30100.3	30715.1	

TE	TE-A	TA-C	TC	DEG C
432.861	431.242	430.762	431.849	

EVAP TEMP	COND TEMP	DELTA-T
434	431.57	2.42993

DPC= 18214   DPG= 0   DPC+DIG= 18214 DYNES/CM2

DPVE	DPLED	DPVA	DPLAG
926	1196	269	9336
DPVC	DPLCG		
-615	4900		

SONIC LIMITS: EVAP= 2314   ADB= 2631   WATTS

Q/A'S=	EVAP	COND	AXIAL	WATTS/CM2
	2	0	142	

E R REY#	E A REY#	LIQ REY#	C A REY#	C R REY#
21	3161	92	3163	5

HOT FLUID CHARGE   92.1796 GRAMS
ROOM TEMP. VOLUME OF HOT FLUID CHARGE   60.1694 CM3

COLD FLUID CHARGE 107.824 GRAMS
                  70.3814 CM3

HEAT PIPE, (MESH) & 2 ENDCAPS 1375.82 GRAMS

DELTA-T VALUES:

EVAP WALL	EVAP LIQ	EVAP MESH	EVAPORATION	
.328831	.352612E-02	.593373E-02	.300293	DEG C

VAPOR (E)	VAPOR (A)	VAPOR (C)
1.61914	.479736	-1.08667

CONDENSATION	COND MESH	COND LIQ	COND WALL	
.073367	.143842E-02	.85473E-03	.202811	DEG C

POWER OF 820 WATTS CAUSES ------------ CAPILLARY LIMIT, DPL > DPV

LAST NON-LIMITED POWER CALCULATION WAS AT ------------ 815 WATTS

------------ TOTAL DELTA-T = 2.87 DEG C
------------ TOTAL MASS = 1.484 KG

RUN CONDITIONS: 11: 8 A.M. 3/28/79

FLUID = RUBIDIUM WALL MATL=304SS
EVAP TEMP = 377 VAPOR DELTA-T = 50 DEG C
GRAV ANG = 0.00 WTG ANG = 0.00 DEG

EVAP LENGTH	16.9291	IN	43.0000	CM
ADB LENGTH	16.9291	IN	43.0000	CM
COND LENGTH	69.2913	IN	176.0000	CM
TOTAL LENGTH	103.1500	IN	262.0000	CM

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O.D.	1.0000	IN	2.5400	CM
WALL THKNSS	0.0100	IN	0.0254	CM
GROOVE WIDTH	0.1083	IN	0.2750	CM
GROOVE HEIGHT	0.0079	IN	0.0200	CM
LAND WIDTH	0.0129	IN	0.0328	CM

25 GROOVES (CLOSED) COVERED WITH 200 MESH

NO LIMIT ENCOUNTERED AT ------------ 514 WATTS

------------ TOTAL DELTA-T = 4.56 DEG C
------------ TOTAL MASS = 0.691 KG

WANT PERFORMANCE DETAILS (Y OR N) ?Y

PE	PE-A	PA-C	PC	DYNES/CM2
10019.5	8848.97	8496.41	9239.51	

TE	TE-A	TA-C	TC	DEG C
376.293	370.666	368.84	372.611	

EVAP TEMP	COND TEMP	DELTA-T
377	372.438	4.56226

DPC= 19133 DPG= 0 DPC+DPG= 19133 DYNES/CM2

DPVE	DPLEG	DPVA	DPLAG
1170	876	353	6860
DPVC	DPLCG		
-745	3597		

SONIC LIMITS: EVAP= 867 ADB= 870 WATTS

Q/A'S=	EVAP	COND	AXIAL	WATTS/CM2
	1	0	101	

E R REY#	E A REY#	LIQ REY#	C A REY#	C R REY#
16	2281	58	2290	3

HOT FLUID CHARGE 95.35 GRAMS
ROOM TEMP. VOLUME OF HOT FLUID CHARGE 62.5663 CM3

COLD FLUID CHARGE 110.102 GRAMS
71.8683 CM3

HEAT PIPE, (MESH) & 2 ENDCAPS 580.457 GRAMS

DELTA-T VALUES:

EVAP WALL	EVAP LAG	EVAP MESH	EVAPORATION	
.201125	.207981E-02	.336022E-02	.500488	DEG C

VAPOR (E)	VAPOR (A)	VAPOR (C)
5.62695	1.32544	-3.77051

CONDENSATION	COND MESH	COND LAG	COND WALL	
.122278	.810205E-03	.501449E-03	.492989E-01	DEG C

POWER OF 710 WATTS CAUSES ------------ ADB SONIC LIMIT

LAST NON-LIMITED POWER CALCULATION WAS AT ------------ 705 WATTS

------------ TOTAL DELTA-T = 6.12 DEG C
------------ TOTAL MASS = 0.691 KG

. CONDITIONS: 4:14 P.M. 4/ 5/79

'ID = DOWTHERM A WALL MATL=304SS
P TEMP = 352 VAPOR DELTA-T = 50 DEG C
V ANG = 0.00 WTO ANG = 0.00 DEG

P . .TH	16.9291	IN	43.0000	CM
LENGTH	16.9291	IN	43.0000	CM
D LENGTH	69.2913	IN	176.0000	CM
'AL LENGTH	103.1500	IN	262.0000	CM

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'.	1.0000	IN	2.5400	CM
L THKNSS	0.0100	IN	0.0254	CM
OVE WIDTH	0.1083	IN	0.2750	CM
OVE HEIGHT	0.0217	IN	0.0550	CM
D WIDTH	0.0094	IN	0.0240	CM

GROOVES (CLOSED) COVERED WITH 200 MESH

LIMIT ENCOUNTERED AT ------------ 440 WATTS

--------- TOTAL DELTA-T = 5.72 DEG C
--- --- TOTAL MASS = 0.777 KG

T PERFORMANCE DETAILS (Y OR N) ?Y

	PE-A	PA-C	PC	DYNES/CM2
33874E+07	.533872E+07	.533871E+07	.533869E+07	

	TE-A	TA-C	TC	DEG C
7.403	347.402	347.402	347.402	

P TEMP	COND TEMP	DELTA-T
2	346.275	5.72485

= 3206 DPG= 0 DPC+DPG= 3206 DYNES/CM2

E	DPLEG	DPVA	DPLAG
	218	6	1426
C	DPLCG		
	894		

IC LIMITS: EVAP= 170527 ADB= 205679 WATTS

'S=	EVAP	COND	AXIAL	WATTS/CM2
	1	0	86	

REY#	E A REY#	LIQ REY#	C A REY#	C R REY#
	764	297	764	1

FLUID CHARGE 123.66 GRAMS
(TEMP. VOLUME OF HOT FLUID CHARGE 115.787 CM3

) FLUID CHARGE 142.992 GRAMS
133.888 CM3

? P! (MESH) & 2 ENDCAPS 634.002 GRAMS

TA-T VALUES:

' WALL	EVAP LEG	EVAP MESH	EVAPORATION	
'5328	3.70969	.611878	.100098	DEG C

IR (E)	VAPOR (A)	VAPOR (C)
15281E-03	.244141E-03	0

DENSATION	COND MESH	COND LEG	COND WALL	
14537E-01	.149562	.909027	.430151E-01	DEG C

.R OF 560 WATTS CAUSES ------------ CAPILLARY LIMIT, DPL > DPV

' NON-LIMITED POWER CALCULATION WAS AT ------------ 555 WATTS

RUN CONDITIONS: 8:49 A.M. 3/30/79 12

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FLUID = DOWTHERM A WALL MATL=304SS
EVAP TEMP = 219 VAPOR DELTA-T = 80 DEG C
GRAV ANG = 0.00 WTG ANG = 0.00 DEG

EVAP LENGTH	16.9291	IN	43.0000	CM
ADB LENGTH	16.9291	IN	43.0000	CM
COND LENGTH	69.2913	IN	176.0000	CM
TOTAL LENGTH	103.1500	IN	262.0000	CM

O.D.	1.0000	IN	2.5400	CM
WALL THKNSS	0.0100	IN	0.0254	CM
GROOVE WIDTH	0.1083	IN	0.2750	CM
GROOVE HEIGHT	0.0217	IN	0.0550	CM
LAND WIDTH	0.0094	IN	0.0240	CM

25 GROOVES (CLOSED) COVERED WITH 200 MESH

NO LIMIT ENCOUNTERED AT ------------ 160 WATTS

------------ TOTAL DELTA-T = 2.49 DEG C
------------ TOTAL MASS = 0.777 KG

WANT PERFORMANCE DETAILS (Y OR N) ?Y

PE	PE-A	PA-C	PC	DYNES/CM2
396240	396219	396194	396170	

TE	TE-A	TA-C	TC	DEG C
217.008	217.006	217.003	217.001	

EVAP TEMP	COND TEMP	DELTA-T
219	216.514	2.48647

DPC= 7280 DPG= 0 DPC+DPG= 7280 DYNES/CM2

DPVE	DPLE	DPVA	DPLA
20	141	17	926
DPVC	DPLC		
24	580		

SONIC LIMITS: EVAP= 16500 ADB= 18735 WATTS

Q/A'S=	EVAP	COND	AXIAL	WATTS/CM2
	0	0	33	

E R REY#	E A REY#	LIQ REY#	C A REY#	C R REY#
2	308	36	308	0

HOT FLUID CHARGE 121.123 GRAMS
ROOM TEMP. VOLUME OF HOT FLUID CHARGE 113.411 CM3

COLD FLUID CHARGE 142.992 GRAMS
133.888 CM3

HEAT PIPE, (MESH) & 2 ENDCAPS 634.002 GRAMS

DELTA-T VALUES:

EVAP WALL	EVAP L&G	EVAP MESH	EVAPORATION	
.746241E-01	1.55778	.259088	.100098	DEG C

VAPOR (E)	VAPOR (A)	VAPOR (C)
.277771E-02	.244141E-02	.244141E-02

CONDENSATION	COND MESH	COND L&G	COND WALL	
.244557E-01	.633176E-01	.381132	.182687E-01	DEG C

POWER OF 715 WATTS CAUSES ------------ CAPILLARY LIMIT, DPL > DPV

LAST NON-LIMITED POWER CALCULATION WAS AT ------------ 710 WATTS

------------ TOTAL DELTA-T = 10.06 DEG C
------------ TOTAL MASS = 0.777 KG

RUN CONDITIONS: 12:58 P.M. 3/27/79

FLUID = MERCURY WALL MATL=304SS
EVAP TEMP = 434 VAPOR DELTA-T = 80 DEG C
GRAV ANG = 0.00 WTG ANG = 0.00 DEG

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EVAP LENGTH	16.9291	IN	43.0000	CM
ADB LENGTH	16.9291	IN	43.0000	CM
COND LENGTH	69.2913	IN	176.0000	CM
TOTAL LENGTH	103.1500	IN	262.0000	CM

O.D.	0.3780	IN	0.9524	CM
WALL THKNSS	0.0039	IN	0.0100	CM
GROOVE WIDTH	0.0787	IN	0.2000	CM
GROOVE HEIGHT	0.0079	IN	0.0200	CM
LAND WIDTH	0.0592	IN	0.1504	CM

8 GROOVES (CLOSED) COVERED WITH 200 MESH

NO LIMIT ENCOUNTERED AT ------------ 720 WATTS

------------ TOTAL DELTA-T = 2.69 DEG C
------------ TOTAL MASS = 0.449 KG

WANT PERFORMANCE DETAILS (Y OR N) ?Y

PE	PE-A	PA-C	PC	DYNES/CM2
.386858E+07	.386703E+07	.386601E+07	.386672E+07	

TE	TE-A	TA-C	TC	DEG C
431.868	431.839	431.82	431.833	

EVAP TEMP	COND TEMP	DELTA-T
434	431.311	2.68872

DPC= 114106 DPG= 0 DPC+DPG= 114106 DYNES/CM2

DPVE	DPLEG	DPVA	DPLAG
1547	6864	1007	81200
DPVC	DPLCG		
-682	28057		

SONIC LIMITS: EVAP= 20097 ADB= 24089 WATTS

Q/A'S=	EVAP	COND	AXIAL	WATTS/CM2
	3	1	1010	

E R REY#	E A REY#	LIQ REY#	C A REY#	C R REY#
13	5074	330	5074	3

HOT FLUID CHARGE 281.891 GRAMS
ROOM TEMP. VOLUME OF HOT FLUID CHARGE 20.8099 CM3

COLD FLUID CHARGE 290.48 GRAMS
21.444 CM3

HEAT PIPE, (MESH) & 2 ENDCAPS 158.596 GRAMS

DELTA-T VALUES:

EVAP WALL	EVAP LIQ	EVAP MESH	EVAPORATION	
.284282	.732296	1.01444	.100098	DEG C

VAPOR (E)	VAPOR (A)	VAPOR (C)
.290527E-01	.192871E-01	-.129396E-01

CONDENSATION	COND MESH	COND LIQ	COND WALL	
.244557E-01	.248109	.179159	.698814E-01	DEG C

POWER OF 935 WATTS CAUSES ------------ CAPILLARY LIMIT, DPL > DPV

LAST NON-LIMITED POWER CALCULATION WAS AT ------------ 930 WATTS

------------ TOTAL DELTA-T = 3.44 DEG C
------------ TOTAL MASS = 0.449 KG

RUN CONDITIONS: 10:41 A.M.   3/30/79

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FLUID = MERCURY   WALL MATL=304SS
EVAP TEMP = 352   VAPOR DELTA-T = 50 DEG C
GRAV ANG = 0.00   WTG ANG = 0.00 DEG

EVAP LENGTH	16.9291	IN	43.0000	CM
ADB LENGTH	16.9291	IN	43.0000	CM
COND LENGTH	69.2913	IN	176.0000	CM
TOTAL LENGTH	103.1500	IN	262.0000	CM

O.D.	0.3750	IN	0.9525	CM
WALL THKNSS	0.0039	IN	0.0100	CM
GROOVE WIDTH	0.0787	IN	0.2000	CM
GROOVE HEIGHT	0.0079	IN	0.0200	CM
LAND WIDTH	0.0592	IN	0.1505	CM

8 GROOVES (CLOSED) COVERED WITH 200 MESH

NO LIMIT ENCOUNTERED AT ---------- 440 WATTS

---------- TOTAL DELTA-T = 1.98 DEG C
---------- TOTAL MASS = 0.449 KG

WANT PERFORMANCE DETAILS (Y OR N) ?Y

PE	PE-A	PA-C	PC	DYNES/CM2
.116902E+07	.116769E+07	.116638E+07	.116681E+07	

TE	TE-A	TA-C	TC	DEG C
350.588	350.437	350.335	350.368	

EVAP TEMP	COND TEMP	DELTA-T
352	350.023	1.97729

DPC= 120072   DPG= 0   DPC+DPG= 120072   DYNES/CM2

DPVE	DPLEG	DPVA	DPLAG
1926	4347	1313	32473
DPVC	DPLCG		
-434	17795		

SONIC LIMITS: EVAP= 6206   ADB= 7012   WATTS

Q/A'S=	EVAP	COND	AXIAL	WATTS/CM2
	3	0	617	

E R REY#	E A REY#	LIQ REY#	C A REY#	C R REY#
9	3479	187	3480	2

HOT FLUID CHARGE   282.835   GRAMS
ROOM TEMP. VOLUME OF HOT FLUID CHARGE   20.8796   CM3

COLD FLUID CHARGE   290.5   GRAMS
                     21.4454   CM3

HEAT PIPE, (MESH) & 2 ENDCAPS 158.621 GRAMS

DELTA-T VALUES:

EVAP WALL	EVAP LEG	EVAP MESH	EVAPORATION	
.184164	.472935	.65448	.100098	DEG C

VAPOR (E)	VAPOR (A)	VAPOR (C)
.150655	.102539	-.336914E-01

CONDENSATION	COND MESH	COND LEG	COND WALL	
.244357E-01	.150059	.115683	.450586E-01	DEG C

POWER OF   305 WATTS CAUSES ---------- CAPILLARY LIMIT, DPL > DPV

LAST NON-LIMITED POWER CALCULATION WAS AT ----------   300 WATTS

---------- TOTAL DELTA-T = 3.83 DEG C
---------- TOTAL MASS = 0.449 KG

RUN CONDITIONS: 1:13 P.M. 3/27/79

FLUID = MERCURY WALL MATL=304SS
EVAP TEMP = 277 VAPOR DELTA-T = 50 DEG C
GRAV ANG = 0.00 WIG ANG = 0.00 DEG

EVAP LENGTH	16.9291 IN	43.0000 CM
ADB LENGTH	16.9291 IN	43.0000 CM
COND LENGTH	69.2913 IN	176.0000 CM
TOTAL LENGTH	103.1500 IN	262.0000 CM

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O.D.	0.3750 IN	0.9524 CM
WALL THKNSS	0.0039 IN	0.0100 CM
GROOVE WIDTH	0.0787 IN	0.2000 CM
GROOVE HEIGHT	0.0079 IN	0.0200 CM
LAND WIDTH	0.0592 IN	0.1504 CM

8 GROOVES (CLOSED) COVERED WITH 200 MESH

NO LIMIT ENCOUNTERED AT ------------ 264 WATTS

------------ TOTAL DELTA-T = 2.08 DEG C
------------ TOTAL MASS = 0.449 KG

WANT PERFORMANCE DETAILS (Y OR N) ?Y

PE	PE-A	PA-C	PC	DYNES/CM2
258510	256701	253728	253630	

TE	TE-A	TA-C	TC	DEG C
276.066	275.542	275.168	275.15	

EVAP TEMP	COND TEMP	DELTA-T
277	274.921	2.0791

DPC= 127000 DPG= 0 DPC+DPG= 127000 DYNES/CM2

DPVE	DPLED	DPVA	DPLAG
2808	2705	1971	20211
DPVC	DPLCG		
98	11077		

SONIC LIMITS: EVAP= 1500 ADB= 1693 WATTS

Q/A'S=	EVAP	COND	AXIAL	WATTS/CM2
	2	0	370	

E R REY#	E A REY#	LIQ REY#	C A REY#	C R REY#
6	2436	105	2441	1

HOT FLUID CHARGE 284.166 GRAMS
ROOM TEMP. VOLUME OF HOT FLUID CHARGE 20.9779 CM3

COLD FLUID CHARGE 290.48 GRAMS
21.444 CM3

HEAT PIPE, (MESH) & 2 ENDCAPS 158.396 GRAMS

DELTA-T VALUES:

EVAP WALL	EVAP LEG	EVAP MESH	EVAPORATION	
.116944	.300587	.416003	.100098	DEG C

VAPOR (E)	VAPOR (A)	VAPOR (C)
.523926	.373779	.135547E-01

CONDENSATION	COND MESH	COND LEG	COND WALL	
.244657E-01	.101781	.735424E-01	.286171E-01	DEG C

POWER OF 310 WATTS CAUSES ------------ CAPILLARY LIMIT, DPL > DPC

LAST NON-LIMITED POWER CALCULATION WAS AT ------------ 305 WATTS

------------ TOTAL DELTA-T = 3.33 DEG C
------------ TOTAL MASS = 0.[illegible] KG

RUN CONDITIONS: 2:57 P.M. 3/27/79

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FLUID = DOWTHERM A WALL MATL=304SS
EVAP TEMP = 352 VAPOR DELTA-T = 50 DEG C
GRAV ANG = 0.00 WIG ANG = 0.00 DEG

EVAP LENGTH	16.9291	IN	43.0000	CM
ADB LENGTH	16.9291	IN	43.0000	CM
COND LENGTH	69.2913	IN	176.0000	CM
TOTAL LENGTH	103.1500	IN	262.0000	CM

O.D.	0.5000	IN	1.2700	CM
WALL THKNSS	0.0050	IN	0.0127	CM
GROOVE WIDTH	0.1083	IN	0.2750	CM
GROOVE HEIGHT	0.0295	IN	0.0750	CM
LAND WIDTH	0.0046	IN	0.0116	CM

12 GROOVES (CLOSED) COVERED WITH 200 MESH

NO LIMIT ENCOUNTERED AT ----------- [illegible] WATTS

----------- TOTAL DELTA-T = 15.04 DEG C
----------- TOTAL MASS = 0.306 KG

WANT PERFORMANCE DETAILS (Y OR N) ?Y

PE	PE-A	PA-C	PC	DYNES/CM2
.474816E+07	.474784E+07	.474760E+07	.474762E+07	

TE	TE-A	TA-C	TC	DEG C
339.936	339.931	339.929	339.928	

EVAP TEMP	COND TEMP	DELTA-T
352	336.959	15.0408

DPC= 3439 DPG= 0 DPC+DPG= 3439 DYNES/CM2

DPVE	DPLEG	DPVA	DPLAG
316	220	146	1330
DPVC	DPLCG		
68	903		

SONIC LIMITS: EVAP= 32664 ADB= 39214 WATTS

Q/A'S=	EVAP	COND	AXIAL	WATTS/CM2
	2	0	347	

E R REY#	E A REY#	LIQ REY#	C A REY#	C R REY#
5	1656	552	1656	1

HOT FLUID CHARGE 66.0229 GRAMS
ROOM TEMP. VOLUME OF HOT FLUID CHARGE 61.8192 CM3

COLD FLUID CHARGE 36.3628 GRAMS
30.8641 CM3

HEAT PIPE, (MESH) & 2 ENDCAPS 219.701 GRAMS

DELTA-T VALUES:

EVAP WALL	EVAP LEG	EVAP MESH	EVAPORATION	
.175328	10.482	1.33651	.100098	DEG C

VAPOR (E)	VAPOR (A)	VAPOR (C)
.430483E-02	.213727E-02	.732422E-03

CONDENSATION	COND MESH	COND LEG	COND WALL	
.244567E-01	.326322	2.87392	.433123E-01	DEG C

POWER OF 515 WATTS CAUSES ------------ CAPILLARY LIMIT, DPL > DPV

LAST NON-LIMITED POWER CALCULATION WAS AT ------------ 510 WATTS

------------ TOTAL DELTA-T = 17.42 DEG C
------------ TOTAL MASS = 0.306 KG

```
FLUID = DOWTHERM A      WALL MATL=304SS
EVAP TEMP =  327        VAPOR DELTA-T =  60  DEG C
GRAV ANG =   0.00       VWG ANG =   0.00  DEG

EVAP  LENGTH    16.9291 IN    43.0000 CM
ADB   LENGTH    16.9291 IN    43.0000 CM
COND  LENGTH    69.2913 IN   176.0000 CM
TOTAL LENGTH   103.1500 IN   262.0000 CM

O.D.             0.5000 IN     1.2700 CM
WALL THKNSS      0.0050 IN     0.0127 CM
GROOVE WIDTH     0.1083 IN     0.2750 CM
GROOVE HEIGHT    0.0256 IN     0.0650 CM
LAND WIDTH       0.0066 IN     0.0168 CM
 12    GROOVES (CLOSED) COVERED WITH 200 MESH


NO LIMIT ENCOUNTERED AT ----------     373 WATTS

---------- TOTAL DELTA-T =    10.73  DEG C
---------- TOTAL MASS    =     0.294 KG

WANT PERFORMANCE DETAILS (Y OR N) ?Y

PE              PE-A            PA-C            PC              DYNES/CM2
 .332091E+07     .332065E+07     .332047E+07     .332037E+07

TE              TE-A            TA-C            TC              DEG C
 318.394         318.388         318.388         318.384

EVAP TEMP       COND TEMP       DELTA-T
 327             316.27          10.7302

DPC= 4112       DPG= 0      DPC+DPG= 4112    DYNES/CM2

DPVE            DPLEG           DPVA            DPLAG
 283             274             150             1722
DPVC            DPLCG
 103             1125

SONIC LIMITS:         EVAP=  24880    ADB=  29826    WATTS

Q/A'S=          EVAP            COND            AXIAL           WATTS/CM2
                 2               0               294

E R REY#        E A REY#        LIQ REY#        C A REY#        C R REY#
 4               1372            405             1372            1

HOT FLUID CHARGE                            60.2462    GRAMS
ROOM TEMP. VOLUME OF HOT FLUID CHARGE       56.4103    CM3

COLD FLUID CHARGE  77.4415  GRAMS
                   72.5108  CM3

HEAT PIPE, (MESH) & 2 ENDCAPS  216.768  GRAMS

DELTA-T VALUES:

EVAP WALL       EVAP LEG        EVAP MESH       EVAPORATION
 .151407         7.22392         1.15017         .100098         DEG C

VAPOR (E)       VAPOR (A)       VAPOR (C)
 .537109E-02     .292969E-02     .195313E-02

CONDENSATION    COND MESH       COND LEG        COND WALL
 .244857E-01     .275341         1.77523         .372896E-01     DEG C


POWER OF    421 WATTS CAUSES ---------- CAPILLARY LIMIT, DPL > DPV

LAST NON-LIMITED POWER CALCULATION WAS AT ----------     420 WATTS

---------- TOTAL DELTA-T =    12.06  DEG C
---------- TOTAL MASS    =     0.294 KG
```

FLUID = DOWTHERM A WALL MATL=304SS
EVAP TEMP = 302 VAPOR DELTA-T = 50 DEG C
GRAV ANG = 0.00 VTS ANG = 0.00 DEG

EVAP LENGTH	16.9291 IN	43.0000 CM
ADB LENGTH	16.9291 IN	43.0000 CM
COND LENGTH	69.2913 IN	176.0000 CM
TOTAL LENGTH	103.1500 IN	262.0000 CM

O.D.	0.5000 IN	1.2700 CM
WALL THKNSS	0.0050 IN	0.0127 CM
GROOVE WIDTH	0.1083 IN	0.2750 CM
GROOVE HEIGHT	0.0236 IN	0.0600 CM
LAND WIDTH	0.0076 IN	0.0194 CM

12 GROOVES (CLOSED) COVERED WITH 200 MESH

NO LIMIT ENCOUNTERED AT ----------- 318 WATTS

----------- TOTAL DELTA-T = 8.38 DEG C
----------- TOTAL MASS = 0.288 KG

WANT PERFORMANCE DETAILS (Y OR N) ?Y

PE	PE-A	PA-C	PC	DYNES/CM2
.222571E+07	.222542E+07	.222521E+07	.222506E+07	

TE	TE-A	TA-C	TC	DEG C
298.287	298.279	298.274	298.271	

EVAP TEMP	COND TEMP	DELTA-T
302	293.623	8.37695

DPC= 4834 DPG= 0 DPC+DPG= 4834 DYNES/CM2

DPVE	DPLED	DPVA	DPLAG
280	305	168	1988
DPVC	DPLCG		
180	1252		

SONIC LIMITS: EVAP= 17710 ADB= 20631 WATTS

Q/A'S=	EVAP	COND	AXIAL	WATTS/CM2
	1	0	248	

E R REY#	E A REY#	LIQ REY#	C A REY#	C R REY#
3	1151	233	1151	0

HOT FLUID CHARGE 57.6718 GRAMS
ROOM TEMP. VOLUME OF HOT FLUID CHARGE 53.3998 CM3

COLD FLUID CHARGE 72.9808 GRAMS
68.3341 CM3

HEAT PIPE, (MESH) & 2 ENDCAPS 214.816 GRAMS

DELTA-T VALUES:

EVAP WALL	EVAP LIQ	EVAP MESH	EVAPORATION	
.130299	6.52068	.362160	.100098	DEG C
VAPOR (E)	VAPOR (A)	VAPOR (C)		
.756836E-02	.488281E-02	.366211E-02		
CONDENSATION	COND MESH	COND LIQ	COND WALL	
.244537E-01	.238245	1.35508	.032033	DEG C

POWER OF 375 WATTS CAUSES ----------- CAPILLARY LIMIT, DPL > DPV

LAST NON-LIMITED POWER CALCULATION WAS AT ----------- 370 WATTS

----------- TOTAL DELTA-T = 9.32 DEG C
----------- TOTAL MASS = 0.288 KG

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RUN CONDITIONS:                                   2:24 P.M.    3/27/79

FLUID = DOWTHERM A       WALL MATL=304SS
EVAP TEMP =  277         VAPOR DELTA-T =  50  DEG C
GRAV ANG =   0.00        VTG ANG =    0.00  DEG

EVAP  LENGTH    16.9291 IN    43.0000 CM
ADB   LENGTH    16.9291 IN    43.0000 CM
COND  LENGTH    69.2913 IN   176.0000 CM
TOTAL LENGTH   103.1500 IN   262.0000 CM

O.D.             0.5000 IN     1.2700 CM
WALL THKNSS      0.0050 IN     0.0127 CM
GROOVE WIDTH     0.1093 IN     0.2780 CM
GROOVE HEIGHT    0.0217 IN     0.0550 CM
LAND WIDTH       0.0087 IN     0.0220 CM
 12    GROOVES (CLOSED) COVERED WITH 200 MESH


NO LIMIT ENCOUNTERED AT ------------     264 WATTS

------------ TOTAL DELTA-T =    6.49  DEG C
------------ TOTAL MASS    =    0.281 KG

WANT PERFORMANCE DETAILS (Y OR N) ?Y

PE              PE-A            PA-C            PC              DYNES/CM2
 .139913E+07     .139889E+07     .139867E+07     .139846E+07

TE              TE-A            TA-C            TC              DEG C
 271.81          271.790         271.701         271.784

EVAP TEMP       COND TEMP       DELTA-T
 277             270.511         6.48877

DPC= 5568       DPG= 0       DPC+DPG= 5568    DYNES/CM2

DPVE            DPLEG           DPVA            DPLAG
 289             361             193             2296
DPVC            DPLCG
 208             1436

SONIC LIMITS.         EVAP=  11918    ADB=  13775    WATTS

Q/A'S=          EVAP            COND            AXIAL           WATTS/CM2
                 1               0               208

E R REY#        E A REY#        LIQ REY#        C A REY#        C R REY#
 3               965             194             965             0

HOT FLUID CHARGE                              55.1152    GRAMS
ROOM TEMP. VOLUME OF HOT FLUID CHARGE         51.606     CM3

COLD FLUID CHARGE   68.5201   GRAMS
                    64.1575   CM3

HEAT PIPE, (MESH) & 2 ENDCAPS  212.537   GRAMS

DELTA-T VALUES:

EVAP WALL       EVAP LEG        EVAP MESH       EVAPORATION
 .111323         1.16533         .313147         .100098         DEG C

VAPOR (E)       VAPOR (A)       VAPOR (C)
 .109863E-01     .756830E-02     .732422E-02

CONDENSATION    COND MESH       COND LEG        COND WALL
 .244507E-01     .19857          1.02143         .273353E-01     DEG C


POWER OF    310 WATTS CAUSES ------------ CAPILLARY LIMIT, DPL > DPV

LAST NON-LIMITED POWER CALCULATION WAS AT ------------    306 WATTS

------------ TOTAL DELTA-T =    7.48  DEG C
------------ TOTAL MASS    =    0.281 KG
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FLUID = DOWTHERM A WALL MATL=304SS
EVAP TEMP = 252 VAPOR DELTA-T = 50 DEG C
GRAV ANG = 0.00 WTG ANG = 0.00 DEG

EVAP LENGTH	16.9291 IN	43.0000 CM
ADB LENGTH	16.9291 IN	43.0000 CM
COND LENGTH	69.2913 IN	176.0000 CM
TOTAL LENGTH	103.1500 IN	262.0000 CM

O.D.	0.5000 IN	1.2700 CM
WALL THKNSS	0.0050 IN	0.0127 CM
GROOVE WIDTH	0.1083 IN	0.2750 CM
GROOVE HEIGHT	0.0197 IN	0.0500 CM
LAND WIDTH	0.0097 IN	0.0247 CM

12 GROOVES (CLOSED) COVERED WITH 200 MESH

NO LIMIT ENCOUNTERED AT ------------ 219 WATTS

------------ TOTAL DELTA-T = 4.98 DEG C
------------ TOTAL MASS = 0.274 KG

WANT PERFORMANCE DETAILS (Y OR N) ?Y

PE	PE-A	PA-C	PC	DYNES/CM2
837793	837486	837235	836952	

TE	TE-A	TA-C	TC	DEG C
248.035	248.017	248.004	247.982	

EVAP TEMP	COND TEMP	DELTA-T
252	247.018	4.98198

DPC= 6311 DPG= 0 DPC+DPG= 6311 DYNES/CM2

DPVE	DPLED	DPVA	DPLAG
307	413	231	2761
DPVC	DPLCG		
283	1693		

SONIC LIMITS: EVAP= 7617 ADD= 8733 WATTS

Q/A'S=	EVAP	COND	AXIAL	WATTS/CM2
	1	0	172	

E R REY#	E A REY#	LIQ REY#	C A REY#	C R REY#
2	806	131	806	0

HOT FLUID CHARGE 52.5281 GRAMS
ROOM TEMP. VOLUME OF HOT FLUID CHARGE 49.1836 CM3

COLD FLUID CHARGE 64.0595 GRAMS
59.9808 CM3

HEAT PIPE, (MESH) & 2 ENDCAPS 209.931 GRAMS

DELTA-T VALUES:

EVAP WALL	EVAP LIQ	EVAP MESH	EVAPORATION	
.941753E-01	3.09005	.681114	.100098	DEG C

VAPOR (E)	VAPOR (A)	VAPOR (C)
.172119E-01	.131836E-01	.148926E-01

CONDENSATION	COND MESH	COND LIQ	COND WALL	
.244557E-01	.166508	.75715	.230995E-01	DEG C

POWER OF 245 WATTS CAUSES ------------ CAPILLARY LIMIT, DPL > DPV

LAST NON-LIMITED POWER CALCULATION WAS AT ------------ 240 WATTS

------------ TOTAL DELTA-T = 5.45 DEG C
------------ TOTAL MASS = 0.274 KG

FLUID = DOWTHERM A WALL MATL=30435
EVAP TEMP = 219 VAPOR DELTA-T = 50 DEG C
GRAV ANG = 0.00 WTG ANG = 0.00 DEG

EVAP LENGTH	16.9291	IN	43.0000	CM
ADB LENGTH	16.9291	IN	43.0000	CM
COND LENGTH	69.2913	IN	176.0000	CM
TOTAL LENGTH	103.1500	IN	262.0000	CM

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O.D.	0.5000	IN	1.2700	CM
WALL THKNSS	0.0050	IN	0.0127	CM
GROOVE WIDTH	0.1083	IN	0.2750	CM
GROOVE HEIGHT	0.0197	IN	0.0500	CM
LAND WIDTH	0.0097	IN	0.0247	CM

12 GROOVES (CLOSED) COVERED WITH 200 MESH

NO LIMIT ENCOUNTERED AT ------------ 169 WATTS

------------ TOTAL DELTA-T = 4.05 DEG C
------------ TOTAL MASS = 0.274 KG

WANT PERFORMANCE DETAILS (Y OR N) ?Y

PE	PE-A	PA-C	PC	DYNES/CM2
384484	384095	383751	383286	

TE	TE-A	TA-C	TC	DEG C
215.845	215.805	215.771	215.724	

EVAP TEMP	COND TEMP	DELTA-T
219	214.952	4.04829

DPC= 7317 DPG= 0 DPC+DPG= 7317 DYNES/CM2

DPVE	DPLEG	DPVA	DPLAG
388	375	334	2505
DPVC	DPLCG		
465	1536		

SONIC LIMITS: EVAP= 3713 ADB= 4207 WATTS

Q/A'S=	EVAP	COND	AXIAL	WATTS/CM2
	0	0	133	

E R REY#	E A REY#	LIQ REY#	C A REY#	C R REY#
2	643	76	543	0

HOT FLUID CHARGE 53.9219 GRAMS
ROOM TEMP. VOLUME OF HOT FLUID CHARGE 50.4887 CM3

COLD FLUID CHARGE 64.0595 GRAMS
59.9808 CM3

HEAT PIPE, (MESH) & 2 ENDCAPS 209.931 GRAMS

DELTA-T VALUES:

EVAP WALL	EVAP LIQ	EVAP MESH	EVAPORATION	
.746241E-01	2.44127	.53893	.100093	DEG C

VAPOR (E)	VAPOR (A)	VAPOR (C)
.398712E-01	.344238E-01	.466309E-01

CONDENSATION	COND MESH	COND LIQ	COND WALL	
.244557E-01	.131746	.397897	.018292	DEG C

POWER OF 220 WATTS CAUSES ------------ CAPILLARY LIMIT, DPL > DPV

LAST NON-LIMITED POWER CALCULATION WAS AT ------------ 215 WATTS

------------ TOTAL DELTA-T = 4.12 DEG C
------------ TOTAL MASS = 0.274 KG

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RUN CONDITIONS:                                      9:36 A.M.    3/30/70

FLUID = MERCURY          WALL MATL=304SS
EVAP TEMP =  434         VAPOR DELTA-T =  30  DEG C
GRAV ANG =   0.00        WTO ANG =   0.00  DEG

EVAP  LENGTH   16.9291 IN    43.0000 CM
ADB   LENGTH   16.9291 IN    43.0000 CM
COND  LENGTH   69.2913 IN   176.0000 CM
TOTAL LENGTH  103.1500 IN   262.0000 CM

O.D.             0.2500 IN     0.6350 CM
WALL THKNSS      0.0025 IN     0.0064 CM
GROOVE WIDTH     0.1083 IN     0.2750 CM
GROOVE HEIGHT    0.0079 IN     0.0200 CM
LAND WIDTH       0.0358 IN     0.0909 CM
 5  GROOVES (CLOSED) COVERED WITH 200 MESH


NO LIMIT ENCOUNTERED AT ------------    720 WATTS

------------ TOTAL DELTA-T =    4.13  DEG C
------------ TOTAL MASS    =    0.290 KG

WANT PERFORMANCE DETAILS (Y OR N) ?Y

PE               PE-A             PA-C             PC               DYNES/CM2
 .381569E+07      .380703E+07      .379924E+07      .380309E+07

TE               TE-A             TA-C             TC               DEG C
 430.878          430.712          430.564          430.637

EVAP TEMP        COND TEMP        DELTA-T
 434              429.872          4.12842

DPC= 114169      DPG= 0      DPC+DPG= 114169     DYNES/CM2

DPVE             DPLEG            DPVA             DPLAG
 8650             7271             7766             56688
DPVC             DPLCG
-3844             29763

SONIC LIMITS:         EVAP=    8444    ADB=   10069    WATTS

Q/A'S=           EVAP             COND             AXIAL            WATTS/CM2
                  8                2                2273

E R REY#         E A REY#         LIQ REY#         C A REY#         C R REY#
 13               7785             393              7787             3

HOT FLUID CHARGE                              206.058    GRAMS
ROOM TEMP. VOLUME OF HOT FLUID CHARGE    15.2117    CM3

COLD FLUID CHARGE  213.035  GRAMS
                    15.7268  CM3

HEAT PIPE. (MESH) & 2 ENDCAPS  76.483   GRAMS

DELTA-T VALUES:

EVAP WALL        EVAP LIQ         EVAP MESH        EVAPORATION
 .270618          1.19874          1.55487          .100098          DEG C

VAPOR (E)        VAPOR (A)        VAPOR (C)
 .153318          .147217          -.725092E-01

CONDENSATION     COND MESH        COND LIQ         COND WALL
 .244557E-01      .380819          .293439          .663033E-01      DEG C


POWER OF    775 WATTS CAUSES ------------ CAPILLARY LIMIT, DPL > DPV

LAST NON-LIMITED POWER CALCULATION WAS AT ------------     770 WATTS

------------ TOTAL DELTA-T =    4.42  DEG C
------------ TOTAL MASS    =    0.290 KG
```

RUN CONDITIONS: 9:44 A.M.   3/30/79

FLUID = MERCURY   WALL MATL=304SS
EVAP TEMP = 402   VAPOR DELTA-T = 50 DEG C
GRAV ANG = 0.00   WTG ANG = 0.00 DEG

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EVAP LENGTH	16.9291	IN	43.0000	CM
ADB LENGTH	16.9291	IN	43.0000	CM
COND LENGTH	69.2913	IN	176.0000	CM
TOTAL LENGTH	103.1500	IN	262.0000	CM

D.	0.2500	IN	0.6350	CM
WALL THKNSS	0.0025	IN	0.0064	CM
GROOVE WIDTH	0.1083	IN	0.2750	CM
GROOVE HEIGHT	0.0079	IN	0.0200	CM
LAND WIDTH	0.0718	IN	0.1823	CM

4 GROOVES (CLOSED) COVERED WITH 200 MESH

NO LIMIT ENCOUNTERED AT ------------ 598 WATTS

------------ TOTAL DELTA-T = 3.62 DEG C
------------ TOTAL MASS = 0.281 KG

WANT PERFORMANCE DETAILS (Y OR N) ?Y

PE	PE-A	PA-C	PC	DYNES/CM2
.239459E+07	.238535E+07	.237686E+07	.238027E+07	

TE	TE-A	TA-C	TC	DEG C
399.401	399.153	398.924	399.016	

EVAP TEMP	COND TEMP	DELTA-T
402	398.379	3.62061

DPC= 116291   DPG= 0   DPC+DPG= 116291   DYNES/CM2

DPVE	DPLEG	DPVA	DPLAG
9242	7655	8462	59687
DPVC	DPLCG		
-3408	31338		

SONIC LIMITS: EVAP= 5424   ADB= 6418   WATTS

Q/A'S=	EVAP	COND	AXIAL	WATTS/CM2
	6	1	1888	

E R REY#	E A REY#	LIQ REY#	C A REY#	C R REY#
11	6726	397	6729	2

HOT FLUID CHARGE   187.61   GRAMS
ROOM TEMP. VOLUME OF HOT FLUID CHARGE   13.8499   CM3

COLD FLUID CHARGE 193.515 GRAMS
                   14.2858 CM3

HEAT PIPE, (MESH) & 2 ENDCAPS 87.8669 GRAMS

DELTA-T VALUES:

EVAP WALL	EVAP L&G	EVAP MESH	EVAPORATION	
.129854	.950525	1.31773	.100098	DEG C

VAPOR (E)	VAPOR (A)	VAPOR (C)
.248291	.229004	-.917969E-01

CONDENSATION	COND MESH	COND L&G	COND WALL	
.244557E-01	.322469	.232703	.562994E-01	DEG C

POWER OF   615 WATTS CAUSES ------------ CAPILLARY LIMIT, DPL > DPV

LAST NON-LIMITED POWER CALCULATION WAS AT ------------ 610 WATTS

------------ TOTAL DELTA-T = 3.69 DEG C
------------ TOTAL MASS = 0.281 KG

```
RUN CONDITIONS:                                   9:52 A.M.    3/30/79

FLUID = MERCURY          WALL MATL=SS403
EVAP TEMP =  352         VAPOR DELTA-T =  50  DEG C
GRAV ANG =   0.00        VTS ANG =   0.00  DEG

EVAP  LENGTH    16.9291 IN    43.0000 CM
ADB   LENGTH    16.9291 IN    43.0000 CM
COND  LENGTH    69.2913 IN   176.0000 CM
TOTAL LENGTH   103.1500 IN   262.0000 CM

O.D.              0.2500 IN     0.6350 CM
WALL THKNSS       0.0025 IN     0.0064 CM
GROOVE WIDTH      0.1083 IN     0.2750 CM
GROOVE HEIGHT     0.0079 IN     0.0200 CM
LAND WIDTH        0.1318 IN     0.3348 CM
 3  GROOVES (CLOSED) COVERED WITH 200 MESH


NO LIMIT ENCOUNTERED AT -----------      440 WATTS

----------- TOTAL DELTA-T =    3.30  DEG C
----------- TOTAL MASS    =    0.273 KG

WANT PERFORMANCE DETAILS (Y OR N) YY

PE              PE-A            PA-C            PC              DYNES/CM2
 .1162621E+07    .1161061E+07    .1141722E+07    .1144255E+07

TE              TE-A            TA-C            TC              DEG C
 350.04          349.883         349.046         349.179

EVAP TEMP       COND TEMP       DELTA-T
 352             348.699         3.30103

DPC= 120118     DPG= 0      DPC+DPG= 120118     DYNES/CM2

DPVE            DPLED           DPVA            DPLAG
 10774           7684            10121           59918
DPVC            DPLCG
-2506            31464

SONIC LIMITS:         EVAP=    2622    ADB=    2921    WATTS

Q/A'S=          EVAP            COND            AXIAL           WATTS/CM2
                 5               1               1389

E R REY#        E A REY#        LIQ REY#        C A REY#        C R REY#
 9               5337            372             5346            2

HOT FLUID CHARGE                                 169.292    GRAMS
ROOM TEMP. VOLUME OF HOT FLUID CHARGE            12.4976    CM3

COLD FLUID CHARGE  173.995  GRAMS
                   12.8448  CM3

HEAT PIPE, (MESH) & 2 ENDCAPS  99.2507  GRAMS

DELTA-T VALUES:

EVAP WALL       EVAP LMG        EVAP MESH       EVAPORATION
 .175328         .680505         1.00319         .100098          DEG C

VAPOR (E)       VAPOR (A)       VAPOR (C)
 .487031         .537354        -.133057

CONDENSATION    COND MESH       COND LMG        COND WALL
 .244557E-01     .215535         .166603         .429384E-01      DEG C


POWER OF    450 WATTS CAUSES ----------- CAPILLARY LIMIT, DPL > DPT

LAST NON-LIMITED POWER CALCULATION WAS AT -----------    445 WATTS

----------- TOTAL DELTA-T =    3.34  DEG C
----------- TOTAL MASS    =    0.273 KG
```

JN CONDITIONS: 9:38 A.M.   4/ 5/79

LUID = MERCURY   WALL MATL=304SS
VAP TEMP = 302   VAPOR DELTA-T = 50 DEG C
RAV ANG = 0.00   WTG ANG = 0.00 DEG

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VAP LENGTH	16.9291 IN	43.0000 CM
DB LENGTH	16.9291 IN	43.0000 CM
OND LENGTH	69.2913 IN	176.0000 CM
OTAL LENGTH	103.1500 IN	262.0000 CM

).D.	0.2500 IN	0.6350 CM
WALL THKNSS	0.0025 IN	0.0064 CM
GROOVE WIDTH	0.1083 IN	0.2750 CM
GROOVE HEIGHT	0.0079 IN	0.0200 CM
LAND WIDTH	0.1318 IN	0.3348 CM

3 GROOVES (CLOSED) COVERED WITH 200 MESH

NO LIMIT ENCOUNTERED AT ------------ 315 WATTS

------------ TOTAL DALTA-T = 4.51 DEG C
------------ TOTAL MASS = 0.273 KG

WANT PERFORMANCE DETAILS (Y OR N) ?Y

PE	PE-A	PA-C	PC	DYNES/CM2
445637	432020	418926	419952	

TE	TE-A	TA-C	TC	DEG C
300.518	299.124	297.747	297.856	

EVAP TEMP	COND TEMP	DELTA-T
302	297.493	4.50708

DPC= 124573   DPG= 0   DPC+DPG= 124573   DYNES/CM2

DPVE	DPLEG	DPVA	DPLAG
13616	5634	13092	43958
DPVC	DPLCG		
-1027	23093		

SONIC LIMITS: EVAP= 1062   ADB= 1146   WATTS

Q/A'S=	EVAP	COND	AXIAL	WATTS/CM2
	3	0	994	

E R REY#	E A REY#	LIQ REY#	C A REY#	C R REY#
7	4208	254	4232	1

HOT FLUID CHARGE   169.89   GRAMS
ROOM TEMP. VOLUME OF HOT FLUID CHARGE   12.5417   CM3

COLD FLUID CHARGE   173.995 GRAMS
                    12.8448 CM3

HEAT PIPE, (MESH) & 2 ENDCAPS   99.2507   GRAMS

DELTA-T VALUES:

EVAP WALL	EVAP LEG	EVAP MESH	EVAPORATION	
.130239	.505764	.745609	.100093	DEG C

VAPOR (E)	VAPOR (A)	VAPOR (C)
1.39453	1.37646	-.109375

CONDENSATION	COND MESH	COND LEG	COND WALL	
.244557E-01	.152729	.123971	.319433E-01	DEG C

POWER OF 390 WATTS CAUSES ------------ CAPILLARY LIMIT, DPL > DPV

LAST NON-LIMITED POWER CALCULATION WAS AT ------------ 385 WATTS

------------ TOTAL DELTA-T = 5.81 DEG C
------------ TOTAL MASS = 0.273 KG

RUN CONDITIONS: 12:29 P.M.   3/30/79

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FLUID = MERCURY   WALL MATL=304SS
EVAP TEMP =   277   VAPOR DELTA-T = 50 DEG C
GRAV ANG =   0.00   WTG ANG =   0.00 DEG

EVAP LENGTH	16.9291 IN	43.0000 CM
ADB LENGTH	16.9291 IN	43.0000 CM
COND LENGTH	69.2913 IN	176.0000 CM
TOTAL LENGTH	103.1500 IN	262.0000 CM

O.D.	0.2500 IN	0.6350 CM
WALL THKNSS	0.0025 IN	0.0064 CM
GROOVE WIDTH	0.1083 IN	0.2750 CM
GROOVE HEIGHT	0.0079 IN	0.0200 CM
LAND WIDTH	0.1318 IN	0.3348 CM

3 GROOVES (CLOSED) COVERED WITH 200 MESH

NO LIMIT ENCOUNTERED AT ------------   264 WATTS

------------ TOTAL DELTA-T =   8.35 DEG C
------------ TOTAL MASS   =   0.273 KG

WANT PERFORMANCE DETAILS (Y OR N) ?Y

PE	PE-A	PA-C	PC	DYNES/CM2
256642	240593	224694	224698	

TE	TE-A	TA-C	TC	DEG C
275.719	272.845	268.961	268.962	

EVAP TEMP	COND TEMP	DELTA-T
277	268.646	8.35382

DPC= 127035   DPG= 0   DPC+DPG= 127035   DYNES/CM2

DPVE	DPLE	DPVA	DPLAG
16048	4781	15896	37334
DPVC	DPLCO		
-4	19636		

SONIC LIMITS: EVAP=   634   ADB=   630   WATTS

Q/A'S=	EVAP	COND	AXIAL	WATTS/CM2
	3	0	833	

E R REY#	E A REY#	LIQ REY#	C A REY#	C R REY#
6	3737	208	3801	1

HOT FLUID CHARGE   170.187   GRAMS
ROOM TEMP. VOLUME OF HOT FLUID CHARGE 12.5636   CM3

COLD FLUID CHARGE 173.995 GRAMS
                   12.8448 CM3

HEAT PIPE, (MESH) & 2 ENDCAPS 99.2507 GRAMS

DELTA-T VALUES:

EVAP WALL	EVAP LIQ	EVAP MESH	EVAPORATION	
.111323	.432317	.837575	.100098	DEG C
VAPOR (E)	VAPOR (A)	VAPOR (C)		
3.17383	3.58325	-.732422E-03		
CONDENSATION	COND MESH	COND LIQ	COND WALL	
.244557E-01	.150789	.106314	.273751E-01	DEG C

POWER OF   350 WATTS CAUSES ------------ CAPILLARY LIMIT, DPL > DPV

LAST NON-LIMITED POWER CALCULATION WAS AT ------------   345 WATTS

------------ TOTAL DELTA-T =   12.83 DEG C
------------ TOTAL MASS   =   0.273 KG

RUN CONDITIONS: 12:46 P.M.   3/30/79

FLUID = MERCURY   WALL MATL=304SS
EVAP TEMP = 434   VAPOR DELTA-T = 60 DEG C
GRAV ANG = 0.00   WTG ANG = 0.00 DEG

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EVAP LENGTH	33.8583 IN	86.0000 CM
ADB LENGTH	0.0000 IN	0.0000 CM
COND LENGTH	69.2913 IN	176.0000 CM
TOTAL LENGTH	103.1800 IN	262.0000 CM
O.D.	0.2504 IN	0.6360 CM
WALL THKNSS	0.0025 IN	0.0064 CM
GROOVE WIDTH	0.1083 IN	0.2750 CM
GROOVE HEIGHT	0.0079 IN	0.0200 CM
LAND WIDTH	0.0360 IN	0.0915 CM

6 GROOVES (CLOSED) COVERED WITH 200 MESH

NO LIMIT ENCOUNTERED AT ------------ 720 WATTS

------------ TOTAL DELTA-T = 2.60 DEG C
------------ TOTAL MASS = 0.290 KG

WANT PERFORMANCE DETAILS (Y OR N) ?Y

PE	PE-A	PA-C	PC	DYNES/CM2
.389659E+07	.388724E+07	.388721E+07	.389094E+07	

TE	TE-A	TA-C	TC	DEG C
432.39	432.216	432.216	432.285	

EVAP TEMP	COND TEMP	DELTA-T
434	431.498	2.50244

DPC= 114073   DPG= 0   DPC+DPG= 114073   DYNES/CM2

DPVE	DPLEG	DPVA	DPLAG
9351	14532	0	0
DPVC	DPLCG		
-3725	29742		

SONIC LIMITS: EVAP= 8646   ADB= 10334   WATTS

Q/A'S=	EVAP	COND	AXIAL	WATTS/CM2
	4	2	2266	

E R REY#	E A REY#	LIQ REY#	C A REY#	C R REY#
6	7758	394	7759	3

HOT FLUID CHARGE   206.234   GRAMS
ROOM TEMP. VOLUME OF HOT FLUID CHARGE   15.2247   CM3

COLD FLUID CHARGE 213.233 GRAMS
                  15.7414 CM3

HEAT PIPE, (MESH) & 2 ENDCAPS 76.7047 GRAMS

DELTA-T VALUES:

EVAP WALL	EVAP LEG	EVAP MESH	EVAPORATION	
.125096	.598018	.775944	.100098	DEG C
VAPOR (E)	VAPOR (A)	VAPOR (C)		
.174072	.483281E-03	-.693359E-01		
CONDENSATION	COND MESH	COND LEG	COND WALL	
.489113E-01	.379483	.292541	.661243E-01	DEG C

POWER OF 1650 WATTS CAUSES ------------ CAPILLARY LIMIT, DPL > DPV

LAST NON-LIMITED POWER CALCULATION WAS AT ------------ 1625 WATTS

------------ TOTAL DELTA-T = 5.47 DEG C
------------ TOTAL MASS = 0.290 KG

RUN CONDITIONS: 12:54 P.M. 3/30/79

FLUID = MERCURY WALL MATL=304SS
EVAP TEMP = 277 VAPOR DELTA-T = 50 DEG C
GRAV ANG = 0.00 VTG ANG = 0.00 DEG

EVAP LENGTH	33.8583 IN	86.0000 CM
ADB LENGTH	0.0000 IN	0.0000 CM
COND LENGTH	69.2913 IN	176.0000 CM
TOTAL LENGTH	103.1500 IN	262.0000 CM

O.D.	0.2500 IN	0.6350 CM
WALL THKNSS	0.0025 IN	0.0064 CM
GROOVE WIDTH	0.1083 IN	0.2750 CM
GROOVE HEIGHT	0.0079 IN	0.0200 CM
LAND WIDTH	0.1318 IN	0.3348 CM

3 GROOVES (CLOSED) COVERED WITH 200 MESH

NO LIMIT ENCOUNTERED AT ------------ 264 WATTS

------------ TOTAL DELTA-T = 4.79 DEG C
------------ TOTAL MASS = 0.273 KG

WANT PERFORMANCE DETAILS (Y OR N) YY

PE	PE-A	PA-C	PC	DYNES/CM2
258631	240821	240817	240617	

TE	TE-A	TA-C	TC	DEG C
276.309	272.592	272.592	272.56	

EVAP TEMP	COND TEMP	DELTA-T
277	272.21	4.78955

DPC= 126975 DPG= 0 DPC+DPG= 126975 DYNES/CM2

DPVE	DPLEG	DPVA	DPLAG
19010	9659	0	0
DPVC	DPLCG		
199	19601		

SONIC LIMITS: EVAP= 641 ADB= 682 WATTS

Q/A'S=	EVAP	COND	AXIAL	WATTS/CM2
	1	0	833	

E R REY#	E A REY#	LIQ REY#	C A REY#	C R REY#
3	3731	208	3766	1

HOT FLUID CHARGE 170.18 GRAMS
ROOM TEMP. VOLUME OF HOT FLUID CHARGE 12.5631 CM3

COLD FLUID CHARGE 173.995 GRAMS
12.8448 CM3

HEAT PIPE, (MESH) & 2 ENDCAPS 99.2507 GRAMS

DELTA-T VALUES:

EVAP WALL	EVAP LIQ	EVAP MESH	EVAPORATION	
.356614E-01	.216152	.318761	.100098	DEG C

VAPOR (E)	VAPOR (A)	VAPOR (C)
3.7168	.732422E-03	.419922E-01

CONDENSATION	COND MESH	COND LIQ	COND WALL	
.489113E-01	.156322	.106007	.272991E-01	DEG C

POWER OF 500 WATTS CAUSED ------------ ADB SONIC LIMIT

LAST NON-LIMITED POWER CALCULATION WAS AT ------------ 495 WATTS

------------ TOTAL DELTA-T = 9.[illegible] DEG C
------------ TOTAL MASS = 0.273 KG

APPENDIX B

HEAT PIPE COOLED NUCLEAR REACTOR DESIGN INFORMATION FROM LOS ALAMOS SCIENTIFIC LABORATORY

(34 Pages)

HEAT-PIPE COOLED NUCLEAR
REACTOR DESIGN INFORMATION
FROM
LOS ALAMOS SCIENTIFIC LABORATORY

This appendix contains the parametric information concerning heat-pipe-cooled reactor weights and sizes for use in the NASA Brayton power plant studies which was supplied by LASL. Data on gas cooled reactors was also furnished but not included herewith since such reactors received only very cursory attention in this study. The mass summary in Figure B-1 indicates that 90%UC-10%ZrC fueled reactors are lighter but more limited in temperature than 60%UO_2-40%Mo fueled reactors. Gas cooled reactors tend to be heavier below 1 MW_t for 90%UC-10%ZrC and 4 MW_t for 60%UO_2-40%Mo.

For heat-pipe reactors, an allowance of 100°K was made for the temperature drop from the reactor heat pipes to the Brayton loop gas. This resulted in analyzing heat pipe reactors 100 degrees higher than the desired turbine inlet temperature. The turbine inlet temperatures AiResearch specified were 1150, 1325, 1500 and 1650°K. The accompanying tabulations provides information at various operating levels. It should be noted that the reactor mass includes one meter of heat pipes beyond the core for use in the heat exchanger but does not include the remainder of the heat exchanger. This mass can be adjusted as needed using the heat pipe mass/unit length values.

Both 90%UC-10%ZrC and 60%UO_2-40%Mo fueled reactors with lifetimes of 10 years at full power were investigated. For the 90%UC-10%ZrC, excessive fuel swelling becomes a problem at 1425°K above 1 MW_t. For lower temperatures and power levels, reactor sizes are limited by criticality and heat transfer considerations. For the region where excess swelling limitations govern, the power density in the fuel must be reduced. A number of means were examined including changing the void fraction in the fuel, reducing the ^{235}U enrichment, adjusting the heat pipe size and modifying the cladding matrix. Adjusting the void fraction will lead to the lowest weight core but at present it is only

an engineering estimate as to how much void can be accepted in a given design. It was concluded that the uncertainties and difficulties in design would not warrant designing a 90%UC-10%ZrC core if the power level and temperature exceeded 2 MW_t and 1425°K since the weight was approaching that of 60%UO_2-40%Mo at these conditions and would probably exceeded it by 4 MW_t.

The 60%UO-40%Mo reactor is criticality and heat transfer limited for the 1425, 1600, and 1750°K outlet temeprature cases except that above 2 MW_t for 1750°K it becomes fuel-swelling limited. Based on our curent best information on fuel swelling, a 4 MW_t reactor operating at 1750°K will have about 14 percent dense fuel swelling.

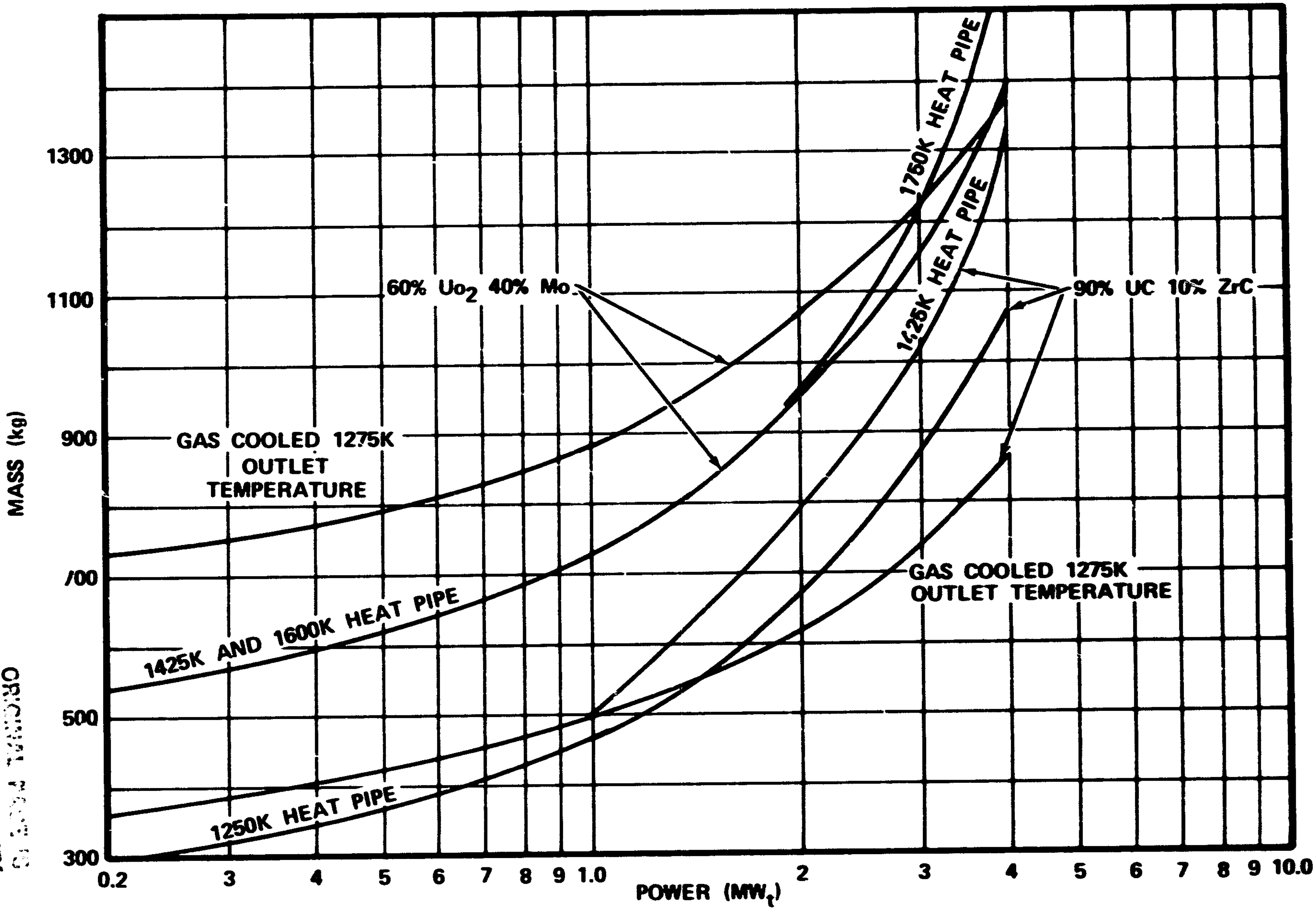

Figure B-1. Reactor Mass Summary.

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                              *********************
 PAGE NO.  2   5-17-78     TYPE NEW INPUT! PP=1, KHP=2 ...STOP
STOP

 0.200 (PP) REACTOR POWER,MW         (KCORE) (1,2/UC,UO2) CORE   =UC
 1250. (THP) HEAT PIPE TEMP,DEG K    (KREF)  (1,2/BE,BEO)  REFLECTOR =BEO
 3650. (TIME) LIFETIME,DAYS          (KHP)(1,2,3/NB,MO,W) HEAT PIPE =MO
  1.00 (FLD) CORE L/D RATIO          (KVAPOR) (1,2/LI,NA) VAPOR     =NA
  10.0 (PAXL) AXIAL HT FLUX,KW/CM2 (IOPTN) (1,2)           OPTION    =2
  200. (DTFMAX) MAX FUEL DELTA T,DEG K
  1.00 (HPL1) PIPE EXTENSION,M
 NOTE, OPTIONS ARE : 1-CODE PT DESIGN, 2-SPECIFIED DESIGN
  TYPE IN ANY OF FOLLOWING : DCORE(M) XREF(M) VNFT FBETA NPIPE ..STOP
NPIPE=84 STOP
                84  (NPIPE) NO. OF HEAT PIPES
       BETA    VC      VCD    ALFA   PKAVG  BMIN   DXMIN  CORGAP ENDGAP
     0.150  0.006  0.050  0.600  1.500  0.050  0.080  0.015  0.005
  TYPE: STOP, OR NEW CONSTANTS IE. VC=0, PKAVG=2, ETC ...STOP
VC=0.012 STOP
 FLD INDEX =      3
 VNF = 0.100 0.200 0.300 0.400 0.500 0.600 0.700 0.800 0.900 1.000
  DC = 0.196 0.208 0.230 0.260 0.299 0.352 0.437 0.595 0.943 *.
 DCH = 0.     0.    0.192 0.135 0.110 0.095 0.085 0.078 0.072 0.067
* * * * * * * * * * * * * * TYPE GO OR START OVER * * * * * * * * * * * * * *
GO...84 PIPES
 BETA =0.1500   VNF =0.2743   VF =0.7257   DX =0.1000   DC =0.2237
 REACTIVITY CHANGES, DELTA K
      BURN = 0.00718 EXP = 0.01512 SAFE = 0.02000 TOTAL = 0.04230
 FUEL ELEMENT VOLUME FRACTIONS
     CLADDING    FUEL REGION    HEAT PIPE    WALL+WICK    VAPOR
      0.0500       0.8642        0.0858       0.0343       0.0515
 HEXAGONAL CORNER CORRECTION FACTOR =1.0082
 NUMBER OF HEAT PIPES =    35.3550
   MINIMUM PRACTICAL (OR SPECIFIED) NUMBER OF HEAT PIPES =    84

 TEMPERATURE SUMMARY,DEGREES KELVIN
      MAXIMUM FUEL DELTA T =   84.2
      AVG DELTA T ACCROSS HEAT PIPE WALL =    4.7
      AVERAGE FUEL TEMPERATURE =1282.8
      MAXIMUM FUEL TEMPERATURE =1341.2
 BURN FRACTION OF U235 =0.0120
 FISSION DENSITY (FISSIONS/CM**3) = 2.492E+20
 FUEL SWELLING,VOLUME % = 0.92
  "          "  , dense fuel % = 1.08
 REACTOR DIMENSIONS, METERS              FUEL ELEMENT DIMENSIONS, MM
   0.2237   CORE DIAMETER                    23.11   WIDTH ACCROSS HEX FLATS
   0.2237   CORE HEIGHT                      24.26   EQUIV. FUEL ELEMENT DIA
   0.4237   REACTOR DIAMETER                 23.65   EQUIV. FUEL REGION O.D.
   0.4337   REACTOR HEIGHT                    7.11   HEAT PIPE O.D.
   0.1000   REFLECTOR THICKNESS               5.51   VAPOR DIAMETER
   1.0000   PIPE LENGTH OUTSIDE REACTOR      23.80   VAPOR AREA, MM**2
   1.3287   TOTAL HEAT PIPE LENGTH
   1.4337   OVERALL REACTOR+HEAT PIPE LENGTH

 REACTOR WEIGHTS, KILOGRAMS
                82.6   FUEL,  U235 MASS =    70.2
               148.7   REFLECTOR
                18.1   HEAT PIPES, WT/UNIT LENGTH (KG/M) =  13.60
                33.0   CONTROL SYSTEM (ASSUME CONSTANT = 33 KG)
                19.8   SUPPORT STRUCTURE (7% OF REACTOR WT)
            ----------
               302.1   TOTAL REACTOR + HEAT PIPES

  26.64 MW/M**3,AVG POWR IN FUELSPACE    2.38 KW,POWER PER HEAT PIPE
 100.03 MW/M**2,HTPIPE AXIAL HT FLUX    0.615 MW/M**2,HTPIPE RAD HTFLX
                              ****************
      TYPE GO OR STOP
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 PROB NO.  3   5-17-78    TYPE NEW INPUT: PR=1, KHP=2 ...STOP
PR=0.4 STOP

 0.400 (PR) REACTOR POWER,MW          (KCORE) (1,2/UC,UO2) CORE   =UC
 1250. (THP) HEAT PIPE TEMP,DEG K     (KREF) (1,2/BE,BEO)  REFLECTOR =BEO
 3650. (TIME) LIFETIME,DAYS           (KHP)(1,2,3/NB,MO,W) HEAT PIPE =MO
  1.00 (SLD) CORE L/D RATIO           (KVAPOR) (1,2/LI,NA) VAPOR     =NA
  10.0 (DAXL) AXIAL HT FLUX,KW/CM2 (IOPTN) (1,2)           OPTION    =2
  200. (DTFMAX) MAX FUEL DELTA T,DEG K
  1.00 (HPL1) PIPE EXTENSION,M
 NOTE, OPTIONS ARE : 1-CODE PT DESIGN; 2-SPECIFIED DESIGN
  TYPE IN ANY OF FOLLOWING : DCORE(M) XREF(M) VNFT FBETA NPIPE ..STOP
NPIPE=84 STOP
                 84  (NPIPE) NO. OF HEAT PIPES
       BETA    VC     VCD    ALFA   PKAVG  BMIN   DXMIN CORGAP ENDGAP
     0.150  0.012  0.050  0.600  1.500  0.050  0.080  0.015  0.005
  TYPE: STOP, OR NEW CONSTANTS IE. VC=0. PKAVG=2. ETC ...STOP
STOP
 SLD INDEX =     3
 VNF = 0.100 0.200 0.300 0.400 0.500 0.600 0.700 0.800 0.900 1.000
  DC = 0.196 0.208 0.230 0.260 0.299 0.352 0.437 0.585 0.943 *.
 DCH = 0.    0.    0.272 0.191 0.156 0.135 0.120 0.110 0.102 0.095
* * * * * * * * * * * * * * TYPE GO OR START OVER * * * * * * * * * * * * * *
GO
 BETA =0.1500   VNF =0.3295   VF =0.6705   DX =0.1000   DC =0.2381
 REACTIVITY CHANGES, DELTA K
      BURN = 0.01288 EXP = 0.01512 SAFE = 0.02000 TOTAL = 0.04800
 FUEL ELEMENT VOLUME FRACTIONS
     CLADDING    FUEL REGION    HEAT PIPE   WALL+WICK    VAPOR
  0.0500       0.7984        0.1516       0.0606        0.0910
 HEXAGONAL CORNER CORRECTION FACTOR =1.0258
 NUMBER OF HEAT PIPES =   48.6978
   MINIMUM PRACTICAL (OR SPECIFIED) NUMBER OF HEAT PIPES =   84

 TEMPERATURE SUMMARY,DEGREE KELVIN
      MAXIMUM FUEL DELTA T = 115.9
      AVG DELTA T ACCROSS HEAT PIPE WALL =   8.8
      AVERAGE FUEL TEMPERATURE =1297.5
      MAXIMUM FUEL TEMPERATURE =1379.2
 BURN FRACTION OF U235 =0.0215
 FISSION DENSITY (FISSIONS/CM**3) = 4.474E+20
 FUEL SWELLING,VOLUME % = 1.86
   "          " ,dense fuel % = 2.19
 REACTOR DIMENSIONS, METERS               FUEL ELEMENT DIMENSIONS, MM
   0.2381   CORE DIAMETER                     24.59  WIDTH ACCROSS HEX FLATS
   0.2381   CORE HEIGHT                       25.82  EQUIV. FUEL ELEMENT DIA
   0.4681   REACTOR DIAMETER                  25.17  EQUIV. FUEL REGION O.D.
   0.4481   REACTOR HEIGHT                    10.05  HEAT PIPE O.D.
   0.1000   REFLECTOR THICKNESS                7.79  VAPOR DIAMETER
   1.0000   PIPE LENGTH OUTSIDE REACTOR       47.64  VAPOR AREA, MM**2
   1.3431   TOTAL HEAT PIPE LENGTH
   1.4481   OVERALL REACTOR+HEAT PIPE LENGTH

 REACTOR WEIGHTS, KILOGRAMS
               92.0  FUEL,  U235 MASS =   78.2
              162.1  REFLECTOR
               36.5  HEAT PIPES, WT/UNIT LENGTH (KG/M) =  27.21
               33.0  CONTROL SYSTEM (ASSUME CONSTANT = 33 KG)
               22.7  SUPPORT STRUCTURE (7% OF REACTOR WT)
          ----------
              346.3  TOTAL REACTOR + HEAT PIPES

  47.83 MW/M**3,AVG POWR IN FUELSPACE   4.76 KW,POWER PER HEAT PIPE
  99.96 MW/M**2,HTPIPE AXIAL HT FLUX    0.817 MW/M**2,HTPIPE RAD HTFLX
                         *********************
     TYPE GO OR STOP
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GO
                         ********************
 PROB NO.  4   5-17-78    TYPE NEW INPUT: PR=1. KHP=2 ...STOP
PR=0.7 STOP

 0.700 (PR) REACTOR POWER,MW          (KCORE) (1,2/UC,UO2) CORE   =UC
 1250. (THP) HEAT PIPE TEMP,DEG K     (KREF) (1,2/BE,BEO)  REFLECTOR =BEO
 3650. (TIME) LIFETIME,DAYS           (KHP)(1,2,3/NB,MO,W) HEAT PIPE =MO
  1.00 (FLD) CORE L/D RATIO           (KVAPOR) (1,2/LI,NA) VAPOR     =NA
  10.0 (QAXL) AXIAL HT FLUX,KW/CM2 (IOPTN) (1,2)          OPTION    =2
  200. (DTFMAX) MAX FUEL DELTA T,DEG K
  1.00 (HPL1) PIPE EXTENSION,M
 NOTE, OPTIONS ARE : 1-CODE PT DESIGN, 2-SPECIFIED DESIGN
  TYPE IN ANY OF FOLLOWING : DCORE(M) XREF(M) VNFT FBETA NPIPE ..STOP
NPIPE=120 STOP
                  120  (NPIPE) NO. OF HEAT PIPES
        BETA    VC      VCD    ALFA    PKAVG   BMIN    DXMIN CORGAP ENDGAP
       0.150  0.012  0.050  0.600  1.500  0.050  0.080  0.015  0.005
  TYPE: STOP, OR NEW CONSTANTS IE. VC=0. PKAVG=2. ETC ...STOP
VC=0.008 STOP
 SLD INDEX =     3
 VNF = 0.100 0.200 0.300 0.400 0.500 0.600 0.700 0.800 0.900 1.000
  DC = 0.196 0.208 0.230 0.260 0.299 0.352 0.437 0.585 0.943 *.
 DCH = 0.    3.484 0.354 0.251 0.205 0.177 0.159 0.145 0.134 0.126
* * * * * * * * * * * * * TYPE GO OR START OVER * * * * * * * * * * * * *
GO
 BETA =0.1500   VNF =0.3905   VF =0.6095   DX =0.1000   DC =0.2568
 REACTIVITY CHANGES, DELTA K
      BURN = 0.01977 EXP = 0.01512 SAFE = 0.02000 TOTAL = 0.05489
 FUEL ELEMENT VOLUME FRACTIONS
     CLADDING    FUEL REGION    HEAT PIPE    WALL+WICK    VAPOR
      0.0500       0.7229        0.2271       0.0908      0.1363
 HEXAGONAL CORNER CORRECTION FACTOR =1.0588
 NUMBER OF HEAT PIPES =    60.6776
   MINIMUM PRACTICAL (OR SPECIFIED) NUMBER OF HEAT PIPES =  120

 TEMPERATURE SUMMARY,DEGREE KELVIN
      MAXIMUM FUEL DELTA T = 10..1
      AVG DELTA T ACCROSS HEAT PIPE WALL =  10.0
      AVERAGE FUEL TEMPERATURE =1293.7
      MAXIMUM FUEL TEMPERATURE =1366.2
 BURN FRACTION OF U235 =0.0329
 FISSION DENSITY (FISSIONS/CM**3) = 6.365E+20
 FUEL SWELLING,VOLUME % = 2.77
   "       "  , dense fuel % = 3.26
 REACTOR DIMENSIONS, METERS            FUEL ELEMENT DIMENSIONS, MM
   0.2568  CORE DIAMETER                    22.24  WIDTH ACCROSS HEX FLATS
   0.2568  CORE HEIGHT                      23.35  EQUIV. FUEL ELEMENT DIA
   0.4868  REACTOR DIAMETER                 22.76  EQUIV. FUEL REGION O.D.
   0.4668  REACTOR HEIGHT                   11.13  HEAT PIPE O.D.
   0.1000  REFLECTOR THICKNESS            .  8.62  VAPOR DIAMETER
   1.0000  PIPE LENGTH OUTSIDE REACTOR      58.34  VAPOR AREA, MM**2
   1.3618  TOTAL HEAT PIPE LENGTH
   1.4668  OVERALL REACTOR+HEAT PIPE LENGTH

 REACTOR WEIGHTS, KILOGRAMS
               104.9  FUEL,  U235 MASS =   89.2
               180.4  REFLECTOR
                64.8  HEAT PIPES, WT/UNIT LENGTH (KG/M) =  47.61
                33.0  CONTROL SYSTEM (ASSUME CONSTANT = 33 KG)
                26.8  SUPPORT STRUCTURE (7% OF REACTOR WT)
           -----------
               409.9  TOTAL REACTOR + HEAT PIPES

  73.39 MW/M**3,AVG POWR IN FUELSPACE   5.83 KW,POWER PER HEAT PIPE
  99.98 MW/M**2,HTPIPE AXIAL HT FLUX    0.839 MW/M**2,HTPIPE RAD HTFLX
                         ********************
      TYPE GO OR STOP
```

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GO
                         ********************
 PROJ NO.  5   5-17-78    TYPE NEW INPUT: PR=1. KHP=2 ...STOP
PR=1. STOP

 1.000 (PR) REACTOR POWER,MW             (KCORE) (1,2/UC,UO2) CORE    =UC
 1250. (THP) HEAT PIPE TEMP,DEG K        (KREF) (1,2/BE,BEO)  REFLECTOR =BEO
 3650. (TIME) LIFETIME,DAYS              (KHP)(1,2,3/NB,MO,W) HEAT PIPE =MO
  1.00 (SLD) CORE L/D RATIO              (KVAPOR) (1,2/LI,NA) VAPOR     =NA
  10.0 (QAXL) AXIAL HT FLUX,KW/CM2 (IOPTN) (1,2)         OPTION    =2
  200. (DTFMAX) MAX FUEL DELTA T,DEG K
  1.00 (HPL1) PIPE EXTENSION,M
 NOTE, OPTIONS ARE : 1-CODE PT DESIGN, 2-SPECIFIED DESIGN
  TYPE IN ANY OF FOLLOWING : DCORE(M) XREF(M) VNFT FBETA NPIPE ..STOP
NPIPE=162 STOP
            162  (NPIPE) NO. OF HEAT PIPES
       BETA    VC     VCD    ALFA    PKAVG   BMIN   DXMIN CORGAP ENDGAP
      0.150  0.008  0.050  0.600  1.500  0.050  0.080  0.015  0.005
  TYPE: STOP, OR NEW CONSTANTS IE. VC=0. PKAVG=2. ETC ...STOP
VC=0.006 STOP
 SLD INDEX =      3
 VNF = 0.100 0.200 0.300 0.400 0.500 0.600 0.700 0.800 0.900 1.000
  DC = 0.196 0.208 0.230 0.260 0.299 0.352 0.437 0.585 0.943 *.
 DCH = 0.    2.606 0.419 0.298 0.244 0.212 0.189 0.173 0.160 0.150
* * * * * * * * * * * * * * TYPE GO OR START OVER * * * * * * * * * * * * * *
GO
 BETA =0.1500   VNF =0.4383   VF =0.5617   DX =0.1000   DC =0.2737
 REACTIVITY CHANGES, DELTA K
     BURN = 0.02533 EXP = 0.01512 SAFE = 0.02000 TOTAL = 0.06045
 FUEL ELEMENT VOLUME FRACTIONS
    CLADDING    FUEL REGION    HEAT PIPE    WALL+WICK    VAPOR
     0.0500       0.6648        0.2852        0.1141       0.1711
 HEXAGONAL CORNER CORRECTION FACTOR =1.0943
 NUMBER OF HEAT PIPES =   68.6911
   MINIMUM PRACTICAL (OR SPECIFIED) NUMBER OF HEAT PIPES =  162

 TEMPERATURE SUMMARY,DEGREE KELVIN
      MAXIMUM FUEL DELTA T =  84.8
      AVG DELTA T ACCROSS HEAT PIPE WALL =   9.9
      AVERAGE FUEL TEMPERATURE =1288.2
      MAXIMUM FUEL TEMPERATURE =1349.7
 BURN FRACTION OF U235 =0.0422
 FISSION DENSITY (FISSIONS/CM**3) = 8.796E+20
 FUEL SWELLING,VOLUME % = 3.39
  "        "  , dense fuel % = 3.99
 REACTOR DIMENSIONS, METERS               FUEL ELEMENT DIMENSIONS, MM
   0.2737  CORE DIAMETER                   20.42  WIDTH ACCROSS HEX FLATS
   0.2737  CORE HEIGHT                     21.44  EQUIV. FUEL ELEMENT DIA
   0.5037  REACTOR DIAMETER                20.89  EQUIV. FUEL REGION O.D.
   0.4837  REACTOR HEIGHT                 ✓11.45  HEAT PIPE O.D.
   0.1000  REFLECTOR THICKNESS            ✓ 8.87  VAPOR DIAMETER
   1.0000  PIPE LENGTH OUTSIDE REACTOR     61.75  VAPOR AREA, MM**2
 ✓ 1.3787  TOTAL HEAT PIPE LENGTH
   1.4837  OVERALL REACTOR+HEAT PIPE LENGTH

 REACTOR WEIGHTS, KILOGRAMS
            117.0  FUEL,  U235 MASS =    99.4
            197.8  REFLECTOR
             93.8  HEAT PIPES, WT/UNIT LENGTH (KG/M) =  68.02
             33.0  CONTROL SYSTEM (ASSUME CONSTANT = 33 KG)
             30.9  SUPPORT STRUCTURE (7% OF REACTOR WT)
         ---------------
            472.5  TOTAL REACTOR + HEAT PIPES

  94.02 MW/M**3,AVG POWR IN FUELSPACE   6.17 KW,POWER PER HEAT PIPE
  99.97 MW/M**2,HTPIPE AXIAL HT FLUX   0.810 MW/M**2,HTPIPE RAD HTFLX
                         ********************
      TYPE GO OR STOP
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GO
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 PROB NO.  6    5-17-78     TYPE NEW INPUT: PR=1. KHP=2 ...STOP
PR=2. STOP

 2.000 (PR) REACTOR POWER,MW          (KCORE) (1,2/UC,UO2) CORE    =UC
 1250. (THP) HEAT PIPE TEMP,DEG K     (KREF)  (1,2/BE,BEO)  REFLECTOR =BEO
 3650. (TIME) LIFETIME,DAYS           (KHP) (1,2,3/NB,MO,W) HEAT PIPE =MO
  1.00 (SLD) CORE L/D RATIO           (KVAPOR) (1,2/LI,NA)  VAPOR     =NA
  10.0 (QAXL) AXIAL HT FLUX,KW/CM2 (IOPTN) (1,2)            OPTION    =2
  200. (DTFMAX) MAX FUEL DELTA T,DEG K
  1.00 (HPL1) PIPE EXTENSION,M
 NOTE, OPTIONS ARE : 1-CODE PT DESIGN, 2-SPECIFIED DESIGN
  TYPE IN ANY OF FOLLOWING : DCORE(M) XREF(M) VNFT PBETA NPIPE ..STOP
NPIPE=210 STOP
                 210  (NPIPE) NO. OF HEAT PIPES
        BETA    VC      VCD    ALFA   PKAVG   BMIN    DXMIN CORGAP ENDGAP
     0.150  0.006  0.050  0.600  1.500  0.050  0.080  0.015  0.005
  TYPE: STOP, OR NEW CONSTANTS IE. VC=0. PKAVG=2. ETC ...STOP
VC=.005 STOP
 SLD INDEX =      3
 VNF = 0.100 0.200 0.300 0.400 0.500 0.600 0.700 0.800 0.900 1.000
  DC = 0.196 0.208 0.230 0.260 0.299 0.352 0.437 0.585 0.943 *.
 DCH = 0.    3.228 0.590 0.421 0.345 0.299 0.268 0.244 0.226 0.212
* * * * * * * * * * * * * TYPE GO OR START OVER * * * * * * * * * * * * *
GO
 BETA =0.1500    VNF =0.5467    VF =0.4533    DX =0.1000    DC =0.3210
 REACTIVITY CHANGES, DELTA K
      BURN = 0.03890 EXP = 0.01512 SAFE = 0.02000 TOTAL = 0.07402
 FUEL ELEMENT VOLUME FRACTIONS
     CLADDING    FUEL REGION    HEAT PIPE    WALL+WICK    VAPOR
     0.0500       0.5360        0.4140       0.1656       0.2484
 HEXAGONAL CORNER CORRECTION FACTOR =1.2092
 NUMBER OF HEAT PIPES =    84.9168
   MINIMUM PRACTICAL (OR SPECIFIED) NUMBER OF HEAT PIPES =  210

 TEMPERATURE SUMMARY,DEGREE KELVIN
      MAXIMUM FUEL DELTA T =   80.9
      AVG DELTA T ACCROSS HEAT PIPE WALL =  13.1
      AVERAGE FUEL TEMPERATURE =1290.0
      MAXIMUM FUEL TEMPERATURE =1350.5
 BURN FRACTION OF U235 =0.0648
 FISSION DENSITY (FISSIONS/CM**3) = 1.351E+21
 FUEL SWELLING,VOLUME % = 5.29
   "       "  , dense fuel % = 6.22
 REACTOR DIMENSIONS, METERS              FUEL ELEMENT DIMENSIONS, MM
   0.3210  CORE DIAMETER                      21.04  WIDTH ACCROSS HEX FLATS
   0.3210  CORE HEIGHT                        22.09  EQUIV. FUEL ELEMENT DIA
   0.5510  REACTOR DIAMETER                   21.54  EQUIV. FUEL REGION O.D.
   0.5310  REACTOR HEIGHT                     14.22  HEAT PIPE O.D.
   0.1000  REFLECTOR THICKNESS                11.01  VAPOR DIAMETER
   1.0000  PIPE LENGTH OUTSIDE REACTOR        95.24  VAPOR AREA, MM**2
   1.4260  TOTAL HEAT PIPE LENGTH
   1.5310  OVERALL REACTOR+HEAT PIPE LENGTH

 REACTOR WEIGHTS, KILOGRAMS
              152.4  FUEL,  U235 MASS =  129.5
              251.5  REFLECTOR
              193.9  HEAT PIPES, WT/UNIT LENGTH (KG/M) = 136.00
               33.0  CONTROL SYSTEM (ASSUME CONSTANT = 33 KG)
               44.2  SUPPORT STRUCTURE (7% OF REACTOR WT)
           ---------
              674.9  TOTAL REACTOR + HEAT PIPES

 144.39 MW/M**3,AVG POWR IN FUELSPACE    9.52 KW,POWER PER HEAT PIPE
 100.00 MW/M**2,HTPIPE AXIAL HT FLUX    0.858 MW/M**2,HTPIPE RAD HTFLX
                                   *********************
9       TYPE GO OR STOP
```

GO

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 PROB NO.  7   5-17-78    TYPE NEW INPUT: PR=1. KHP=2 ...STOP
PR=4. STOP

 4.000 (PR) REACTOR POWER,MW          (KCORE) (1,2/UC,UO2) CORE     =UC
 1250. (THP) HEAT PIPE TEMP,DEG K     (KREF)  (1,2/BE,BEO) REFLECTOR =BEO
 3650. (TIME) LIFETIME,DAYS           (KHP)(1,2,3/NB,MO,W) HEAT PIPE =MO
  1.00 (SLD) CORE L/D RATIO           (KVAPOR) (1,2/LI,NA) VAPOR     =NA
  10.0 (QAXL) AXIAL HT FLUX,KW/CM2 (IOPTN) (1,2)           OPTION    =2
  200. (DTFMAX) MAX FUEL DELTA T,DEG K
  1.00 (HPL1) PIPE EXTENSION,M
 NOTE, OPTIONS ARE : 1-CODE PT DESIGN, 2-SPECIFIED DESIGN
  TYPE IN ANY OF FOLLOWING : DCORE(M) XREF(M) VNFT FBETA NPIPE ..STOP
NPIPE=264 STOP
              264  (NPIPE) NO. OF HEAT PIPES
        BETA    VC     VCD    ALFA   PKAVG   BMIN   DXMIN CORGAP ENDGAP
     0.150  0.005  0.050  0.600  1.500  0.050  0.080  0.015  0.005
  TYPE: STOP, OR NEW CONSTANTS IE. VC=0. PKAVG=2. ETC ...STOP
VC=0.004 STOP
 SLD INDEX =     3
 VNF = 0.100 0.200 0.300 0.400 0.500 0.600 0.700 0.800 0.900 1.000
  DC = 0.196 0.208 0.230 0.260 0.299 0.352 0.437 0.585 0.943 *.
 DCH = 0.    4.111 0.832 0.594 0.487 0.422 0.378 0.346 0.320 0.300
* * * * * * * * * * * * TYPE GO OR START OVER * * * * * * * * * * * *
GO
 BETA =0.1500   VNF =0.6570   VF =0.3430   DX =0.1000   DC =0.3954
 REACTIVITY CHANGES, DELTA K
      BURN = 0.05500 EXP = 0.01512 SAFE = 0.02000 TOTAL = 0.09012
 FUEL ELEMENT VOLUME FRACTIONS
     CLADDING    FUEL REGION    HEAT PIPE    WALL+WICK    VAPOR
     0.0500        0.4051        0.5449        0.2180       0.3269
 HEXAGONAL CORNER CORRECTION FACTOR =1.3895
 NUMBER OF HEAT PIPES =  101.8710
   MINIMUM PRACTICAL (OR SPECIFIED) NUMBER OF HEAT PIPES =  264

 TEMPERATURE SUMMARY,DEGREE KELVIN
      MAXIMUM FUEL DELTA T =  77.2
      AVG DELTA T ACCROSS HEAT PIPE WALL =  16.9
      AVERAGE FUEL TEMPERATURE =1292.6
      MAXIMUM FUEL TEMPERATURE =1352.5
 BURN FRACTION OF U235 =0.0917
 FISSION DENSITY (FISSIONS/CM**3) = 1.910E+21
 FUEL SWELLING,VOLUME % = 7.64
  "        "     , dense fuel % = 8.99
 REACTOR DIMENSIONS, METERS              FUEL ELEMENT DIMENSIONS, MM
   0.3954  CORE DIAMETER                      23.13  WIDTH ACCROSS HEX FLATS
   0.3954  CORE HEIGHT                        24.29  EQUIV. FUEL ELEMENT DIA
   0.6254  REACTOR DIAMETER                   23.67  EQUIV. FUEL REGION O.D.
   0.6054  REACTOR HEIGHT                     17.93  HEAT PIPE O.D.
   0.1000  REFLECTOR THICKNESS                13.89  VAPOR DIAMETER
   1.0000  PIPE LENGTH OUTSIDE REACTOR       151.46  VAPOR AREA, MM**2
   1.5004  TOTAL HEAT PIPE LENGTH
   1.6054  OVERALL REACTOR+HEAT PIPE LENGTH

 REACTOR WEIGHTS, KILOGRAMS
              215.5  FUEL,  U235 MASS =  183.2
              350.0  REFLECTOR
              408.0  HEAT PIPES, WT/UNIT LENGTH (KG/M) = 271.90
               33.0  CONTROL SYSTEM (ASSUME CONSTANT = 33 KG)
               70.5  SUPPORT STRUCTURE (7% OF REACTOR WT)
           ----------
             1076.9  TOTAL REACTOR + HEAT PIPES

 204.17 MW/M**3,AVG POWR IN FUELSPACE  15.15 KW,POWER PER HEAT PIPE
 100.04 MW/M**2,HTPIPE AXIAL HT FLUX    0.878 MW/M**2,HTPIPE RAD HTFLX
                    ********************
     TYPE GO OR STOP
```

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                                   ********************
 PROB NO.  8   5-17-78     TYPE NEW INPUT: PR=1. KHP=2 ...STOP
PR=0.2 THP=1425. STOP

 0.200 (PR) REACTOR POWER,MW            (KCORE) (1,2/UC,UO2) CORE   =UC
 1425. (THP) HEAT PIPE TEMP,DEG K       (KREF) (1,2/BE,BEO)  REFLECTOR =BEO
 3650. (TIME) LIFETIME,DAYS             (KHP)(1,2,3/NB,MO,W) HEAT PIPE =MO
  1.00 (SLD) CORE L/D RATIO             (KVAPOR) (1,2/LI,NA) VAPOR     =NA
  10.0 (QAXL) AXIAL HT FLUX,KW/CM2 (IOPTN) (1,2)             OPTION    =2
  200. (DTFMAX) MAX FUEL DELTA T,DEG K
  1.00 (HPL1) PIPE EXTENSION,M
 NOTE, OPTIONS ARE : 1-CODE PT DESIGN, 2-SPECIFIED DESIGN
  TYPE IN ANY OF FOLLOWING : DCORE(M) XREF(M) VNFT FBETA NPIPE ..STOP
NPIPE=84 STOP
               84  (NPIPE) NO. OF HEAT PIPES
      BETA    VC     VCD    ALFA   PKAVG   BMIN   DXMIN CORGAP ENDGAP
     0.150  0.004  0.050  0.600  1.500  0.050  0.080  0.015  0.005
  TYPE: STOP, OR NEW CONSTANTS IE. VC=0. PKAVG=2. ETC ...STOP
VC=.012 STOP
 SLD INDEX =     3
 VNF = 0.100 0.200 0.300 0.400 0.500 0.600 0.700 0.800 0.900 1.000
  DC = 0.196 0.208 0.230 0.260 0.299 0.352 0.437 0.585 0.943 *.
 DCH = 0.    0.    0.192 0.135 0.110 0.095 0.085 0.078 0.072 0.067
* * * * * * * * * * * * * TYPE GO OR START OVER * * * * * * * * * * * * *
GO
 BETA =0.1500   VNF =0.2743   VF =0.7257   DX =0.1000   DC =0.2237
 REACTIVITY CHANGES, DELTA K
      BURN = 0.00718 EXP = 0.01764 SAFE = 0.02000 TOTAL = 0.04482
 FUEL ELEMENT VOLUME FRACTIONS
    CLADDING    FUEL REGION    HEAT PIPE    WALL+WICK    VAPOR
     0.0500       0.8642        0.0858       0.0343      0.0515
 HEXAGONAL CORNER CORRECTION FACTOR =1.0082
 NUMBER OF HEAT PIPES =    35.3550
   MINIMUM PRACTICAL (OR SPECIFIED) NUMBER OF HEAT PIPES =    84

 TEMPERATURE SUMMARY,DEGREE KELVIN
      MAXIMUM FUEL DELTA T =  84.2
      AVG DELTA T ACCROSS HEAT PIPE WALL =    4.7
      AVERAGE FUEL TEMPERATURE =1457.8
      MAXIMUM FUEL TEMPERATURE =1516.2
 BURN FRACTION OF U235 =0.0120
 FISSION DENSITY (FISSIONS/CM**3) = 2.492E+20
 FUEL SWELLING,VOLUME % = 3.27
  "       "      , dense fuel % = 3.85
 REACTOR DIMENSIONS, METERS              FUEL ELEMENT DIMENSIONS, MM
   0.2237  CORE DIAMETER                    23.11  WIDTH ACCROSS HEX FLATS
   0.2237  CORE HEIGHT                      24.26  EQUIV. FUEL ELEMENT DIA
   0.4537  REACTOR DIAMETER                 23.65  EQUIV. FUEL REGION O.D.
   0.4337  REACTOR HEIGHT                    7.11  HEAT PIPE O.D.
   0.1000  REFLECTOR THICKNESS               5.51  VAPOR DIAMETER
   1.0000  PIPE LENGTH OUTSIDE REACTOR      23.80  VAPOR AREA, MM**2
   1.3287  TOTAL HEAT PIPE LENGTH
   1.4337  OVERALL REACTOR+HEAT PIPE LENGTH

 REACTOR WEIGHTS, KILOGRAMS
               82.6  FUEL,  U235 MASS =    70.2
              148.7  REFLECTOR
               18.1  HEAT PIPES, WT/UNIT LENGTH (KG/M) =  13.60
               33.0  CONTROL SYSTEM (ASSUME CONSTANT = 33 KG)
               19.8  SUPPORT STRUCTURE (7% OF REACTOR WT)
            --------
              302.1  TOTAL REACTOR + HEAT PIPES

  26.64 MW/M**3,AVG POWR IN FUELSPACE    2.38 KW,POWER PER HEAT PIPE
 100.03 MW/M**2,HTPIPE AXIAL HT FLUX    0.615 MW/M**2,HTPIPE RAD HTFLX
                                   ********************
      TYPE GO OR STOP
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GO
                    ********************
 PROP NO.  9   5-17-78    TYPE NEW INPUT: PR=1. KHP=2 ...STOP
PR=0.4 STOP

 0.400 (PR) REACTOR POWER,MW          (KCORE) (1,2/UC,UO2) CORE      =UC
 1425. (THP) HEAT PIPE TEMP,DEG K     (KREF) (1,2/BE,BEO)  REFLECTOR =BEO
 3650. (TIME) LIFETIME,DAYS           (KHP) (1,2,3/NB,MO,W) HEAT PIPE =MO
  1.00 (SLD) CORE L/D RATIO           (KVAPOR) (1,2/LI,NA) VAPOR     =NA
  10.0 (QAXL) AXIAL HT FLUX,KW/CM2 (IOPTN) (1,2)           OPTION    =2
  200. (DTFMAX) MAX FUEL DELTA T,DEG K
  1.00 (HPL1) PIPE EXTENSION,M
 NOTE, OPTIONS ARE : 1--CODE PT DESIGN, 2-SPECIFIED DESIGN
  TYPE IN ANY OF FOLLOWING : DCORE(M) XREF(M) VNFT FBETA NPIPE ..STOP
NPIPE=84 STOP
                 84  (NPIPE) NO. OF HEAT PIPES
       BETA    VC     VCD    ALFA   PKAVG   BMIN   DYMIN CORGAP ENDGAP
      0.150  0.012  0.050  0.600  1.500  0.050  0.080  0.015  0.005
  TYPE: STOP, OR NEW CONSTANTS IE. VC=0. PKAVG=2. ETC ...STOP
STOP
 SLD INDEX =    3
 VNF = 0.100 0.200 0.300 0.400 0.500 0.600 0.700 0.800 0.900 1.000
  DC = 0.196 0.208 0.230 0.260 0.299 0.352 0.437 0.585 0.943 *.
 DCH = 0.    0.    0.272 0.191 0.156 0.135 0.120 0.110 0.102 0.095
* * * * * * * * * * * * TYPE GO OR START OVER * * * * * * * * * * * * *
GO
 BETA =0.1500   VNF =0.3295   VF =0.6705   DX =0.1000   DC =0.2381
 REACTIVITY CHANGES, DELTA K
     BURN = 0.01288 EXP = 0.01764 SAFE = 0.02000 TOTAL = 0.05052
 FUEL ELEMENT VOLUME FRACTIONS
    CLADDING   FUEL REGION   HEAT PIPE   WALL+WICK   VAPOR
     0.0500      0.7984       0.1516      0.0606      0.0910
 HEXAGONAL CORNER CORRECTION FACTOR =1.0258
 NUMBER OF HEAT PIPES =   48.6978
   MINIMUM PRACTICAL (OR SPECIFIED) NUMBER OF HEAT PIPES =   84

 TEMPERATURE SUMMARY,DEGREE KELVIN
     MAXIMUM FUEL DELTA T = 115.9
     AVG DELTA T ACCROSS HEAT PIPE WALL =   8.8
     AVERAGE FUEL TEMPERATURE =1472.5
     MAXIMUM FUEL TEMPERATURE =1554.2
 BURN FRACTION OF U235 =0.0215
 FISSION DENSITY (FISSIONS/CM**3) = 4.474E+20
 FUEL SWELLING,VOLUME % = 6.44
  "     "     dense fuel % = 7.58
 REACTOR DIMENSIONS, METERS              FUEL ELEMENT DIMENSIONS, MM
   0.2381   CORE DIAMETER                     24.59  WIDTH ACCROSS HEX FLATS
   0.2381   CORE HEIGHT                       25.82  EQUIV. FUEL ELEMENT DIA
   0.4681   REACTOR DIAMETER                  25.17  EQUIV. FUEL REGION O.D.
   0.4481   REACTOR HEIGHT                    10.05  HEAT PIPE O.D.
   0.1000   REFLECTOR THICKNESS                7.79  VAPOR DIAMETER
   1.0000   PIPE LENGTH OUTSIDE REACTOR       47.64  VAPOR AREA, MM**2
   1.3431   TOTAL HEAT PIPE LENGTH
   1.4481   OVERALL REACTOR+HEAT PIPE LENGTH

 REACTOR WEIGHTS, KILOGRAMS
               92.0  FUEL,  U235 MASS =    78.2
              162.1  REFLECTOR
               36.5  HEAT PIPES, WT/UNIT LENGTH (KG/M) =  27.21
               33.0  CONTROL SYSTEM (ASSUME CONSTANT = 33 KG)
               22.7  SUPPORT STRUCTURE (7% OF REACTOR WT)
          ----------
              346.3  TOTAL REACTOR + HEAT PIPES

 47.83 MW/M**3,AVG POWR IN FUELSPACE   4.76 KW,POWER PER HEAT PIPE
 99.96 MW/M**2,HTPIPE AXIAL HT FLUX    0.817 MW/M**2,HTPIPE RAD HTFLX
                    ********************
      TYPE GO OR STOP
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PROB NO. 10   5-17-78    TYPE NEW INPUT! PR=1. KHP=2 ...STOP
PR=0.7 STOP

 0.700 (PR) REACTOR POWER,MW          (KCORE) (1,2/UC,UO2) CORE     =UC
 1425. (THP) HEAT PIPE TEMP,DEG K     (KREF) (1,2/BE,BEO)  REFLECTOR =BEO
 3630. (TIME) LIFETIME,DAYS           (KHP)(1,2,3/NB,MO,W) HEAT PIPE =MO
  1.00 (SLD) CORE L/D RATIO           (KVAPOR) (1,2/LI,NA) VAPOR     =NA
  10.0 (QAXL) AXIAL HT FLUX,KW/CM2 (IOPTN) (1,2)            OPTION    =2
  200. (DTFMAX) MAX FUEL DELTA T,DEG K
  1.00 (HPL1) PIPE EXTENSION,M
 NOTE, OPTIONS ARE ! 1-CODE PT DESIGN, 2-SPECIFIED DESIGN
  TYPE IN ANY OF FOLLOWING ! DCORE(M) XREF(M) VNFT FBETA NPIPE ..STOP
NPIPE=120 STOP
              120   (NPIPE) NO. OF HEAT PIPES
        BETA    VC     VCD    ALFA   PKAVG   BMIN   DXMIN CORGAP ENDGAP
     0.150  0.012  0.050  0.600  1.500  0.050  0.080  0.015  0.005
 TYPE: STOP, OR NEW CONSTANTS IE. VC=0. PKAVG=2. ETC ...STOP
VC=0.008 STOP
 SLD INDEX =     3
 VNF = 0.100 0.200 0.300 0.400 0.500 0.600 0.700 0.800 0.900 1.000
  DC = 0.196 0.208 0.230 0.260 0.299 0.352 0.437 0.585 0.943 *.
 DCH = 0.     3.484 0.354 0.251 0.205 0.177 0.159 0.145 0.134 0.126
* * * * * * * * * * * * * * TYPE GO OR START OVER * * * * * * * * * * * * * *
GO
 BETA =0..500   VNF =0.3905   VF =0.6095   DX =0.1000   DC =0.2568
 REACTIVITY CHANGES, DELTA K
      BURN = 0.01977 EXP = 0.01764 SAFE = 0.02000 TOTAL = 0.05741
 FUEL ELEMENT VOLUME FRACTIONS
     CLADDING   FUEL REGION   HEAT PIPE   WALL+WICK    VAPOR
      0.0500      0.7229       0.2271      0.0908      0.1363
 HEXAGONAL CORNER CORRECTION FACTOR =1.0588
 NUMBER OF HEAT PIPES =    60.6776
   MINIMUM PRACTICAL (OR SPECIFIED) NUMBER OF HEAT PIPES =  120

 TEMPERATURE SUMMARY,DEGREE KELVIN
      MAXIMUM FUEL DELTA T = 101.1
      AVG DELTA T ACCROSS HEAT PIPE WALL =  10.0
      AVERAGE FUEL TEMPERATURE =1468.7
      MAXIMUM FUEL TEMPERATURE =1541.2
 BURN FRACTION OF U235 =0.0329
 FISSION DENSITY (FISSIONS/CM**3) = 6.865E+20
 FUEL SWELLING,VOLUME % = 9.65
  "      "    , dense fuel % = 11.35
 REACTOR DIMENSIONS, METERS               FUEL ELEMENT DIMENSIONS, MM
   0.2568  CORE DIAMETER                       22.24  WIDTH ACCROSS HEX FLATS
   0.2568  CORE HEIGHT                         23.35  EQUIV. FUEL ELEMENT DIA
   0.4868  REACTOR DIAMETER                    22.76  EQUIV. FUEL REGION O.D.
   0.4668  REACTOR HEIGHT                      11.13  HEAT PIPE O.D.
   0.1000  REFLECTOR THICKNESS                  8.62  VAPOR DIAMETER
   1.0000  PIPE LENGTH OUTSIDE REACTOR         58.34  VAPOR AREA, MM**2
   1.3618  TOTAL HEAT PIPE LENGTH
   1.4668  OVERALL REACTOR+HEAT PIPE LENGTH

 REACTOR WEIGHTS, KILOGRAMS
              104.9  FUEL,  U235 MASS =   89.2
              180.4  REFLECTOR
               64.8  HEAT PIPES, WT/UNIT LENGTH (KG/M) =  47.61
               33.0  CONTROL SYSTEM (ASSUME CONSTANT = 33 KG)
               26.8  SUPPORT STRUCTURE (7% OF REACTOR WT)
            -------
              409.9  TOTAL REACTOR + HEAT PIPES

  73.39 MW/M**3,AVG POWR IN FUELSPACE    5.83 KW,POWER PER HEAT PIPE
  99.99 MW/M**2,HTPIPE AXIAL HT FLUX    0.839 MW/M**2,HTPIPE RAD HTFLX
                    ********************
     TYPE GO OR STOP
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                          ◆◆◆◆◆◆◆◆◆◆◆◆◆◆◆◆◆◆◆◆◆
 PAGE NO. 13    5-17-78     TYPE NEW INPUT! PR=1. KHP=2 ...STOP
STOP

 1.000 (PR) REACTOR POWER,MW          (ICORE) (1,2/UC,UO2) CORE    =UC
 1425. (THP) HEAT PIPE TEMP,DEG K     (KREF) (1,2/BE,BEO)  REFLECTOR =BEO
 3650. (TIME) LIFETIME,DAYS           (KHP)(1,2,3/NB,MO,W) HEAT PIPE =MO
  1.00 (ELD) CORE L/D RATIO           (KVAPOR) (1,2/LI,NA) VAPOR     =NA
  10.0 (RAXL) AXIAL HT FLUX,KW/CM2 (IOPTN) (1,2)           OPTION    =2
  200. (DTFMAX) MAX FUEL DELTA T,DEG K
  1.00 (HPL1) PIPE EXTENSION,M
 NOTE, OPTIONS ARE : 1-CODE PT DESIGN, 2-SPECIFIED DESIGN
  TYPE IN ANY OF FOLLOWING : DCORE(M) XREF(M) VNFT FSETA NPIPE ..STOP
NPIPE=162 STOP
                162  (NPIPE) NO. OF HEAT PIPES
        BETA    VC      VCD    ALFA    PKAVG   BMIN    DXMIN CORGAP ENDGAP
      0.200  0.006  0.050  0.600  1.500  0.050  0.080  0.015  0.005
  TYPE: STOP, OR NEW CONSTANTS IE. VC=0. PKAVG=2. ETC ...STOP
BETA=0.25 STOP
 ELD INDEX =     3
 VNF = 0.100 0.200 0.300 0.400 0.500 0.600 0.700 0.800 0.900 1.000
  DC = 0.196 0.208 0.230 0.260 0.299 0.352 0.437 0.585 0.943 *.
 DCH = 0.    0.    1.391 0.383 0.276 0.227 0.197 0.177 0.162 0.150
◆ ◆ ◆ ◆ ◆ ◆ ◆ ◆ ◆ ◆ ◆ ◆ ◆ TYPE GO OR START OVER ◆ ◆ ◆ ◆ ◆ ◆ ◆ ◆ ◆ ◆ ◆ ◆ ◆
GO...ADJUST BETA FOR 10% SWELLING
 BETA =0.2500    VNF =0.4804    VF =0.5196    DX =0.1000    DC =0.2904
 REACTIVITY CHANGES, DELTA K
      BURN = 0.02290 EXP = 0.01764 SAFE = 0.02000 TOTAL = 0.06054
 FUEL ELEMENT VOLUME FRACTIONS
     CLADDING    FUEL REGION    HEAT PIPE    WALL+WICK    VAPOR
      0.0500       0.6970        0.2530       0.1012       0.1518
 HEXAGONAL CORNER CORRECTION FACTOR =1.0735
 NUMBER OF HEAT PIPES =    70.8802
   MINIMUM PRACTICAL (OR SPECIFIED) NUMBER OF HEAT PIPES =   162

 TEMPERATURE SUMMARY,DEGREE KELVIN
      MAXIMUM FUEL DELTA T =  87.5
      AVG DELTA T ACCROSS HEAT PIPE WALL =    9.4
      AVERAGE FUEL TEMPERATURE =1463.5
      MAXIMUM FUEL TEMPERATURE =1526.6
 BURN FRACTION OF U235 =0.0382
 FISSION DENSITY (FISSIONS/CM**3) = 7.017E+20
 FUEL SWELLING,VOLUME % = 9.54
   "       "  ,dense fuel % = 12.72
 REACTOR DIMENSIONS, METERS                 FUEL ELEMENT DIMENSIONS, MM
  0.2904   CORE DIAMETER                      21.67   WIDTH ACCROSS HEX FLATS
  0.2904   CORE HEIGHT                        22.75   EQUIV. FUEL ELEMENT DIA
  0.5204   REACTOR DIAMETER                   22.18   EQUIV. FUEL REGION O.D.
  0.5004   REACTOR HEIGHT                     11.44   HEAT PIPE O.D.
  0.1000   REFLECTOR THICKNESS                 8.86   VAPOR DIAMETER
  1.0000   PIPE LENGTH OUTSIDE REACTOR        61.71   VAPOR AREA, MM**2
  1.3954   TOTAL HEAT PIPE LENGTH
  1.5004   OVERALL REACTOR+HEAT PIPE LENGTH

 REACTOR WEIGHTS, KILOGRAMS
                129.4   FUEL,  U235 MASS =  110.0
                216.1   REFLECTOR
                 94.9   HEAT PIPES, WT/UNIT LENGTH (KG/M) =  67.98
                 33.0   CONTROL SYSTEM (ASSUME CONSTANT = 33 KG)
                 33.1   SUPPORT STRUCTURE (7% OF REACTOR WT)
           ---------
                506.4   TOTAL REACTOR + HEAT PIPES

  75.01 MW/M**3,AVG POWR IN FUELSPACE    6.17 KW,POWER PER HEAT PIPE
 100.02 MW/M**2,HTPIPE AXIAL HT FLUX    0.763 MW/M**2,HTPIPE RAD HTFLX
                          ◆◆◆◆◆◆◆◆◆◆◆◆◆◆◆◆◆◆◆◆◆
      TYPE GO OR STOP
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ORIGINAL PAGE IS OF POOR QUALITY

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PROP NO. 16    5-17-78     TYPE NEW INPUT: PR=1. KHP=2 ...STOP
STOP

 2.000 (PR) REACTOR POWER,MW          (KCORE)  (1,2/UC,UO2)  CORE    =UC
 1425. (THP) HEAT PIPE TEMP,DEG K     (KREF)  (1,2/BE,BEO)   REFLECTOR =BEO
 3650. (TIME) LIFETIME,DAYS           (KHP)(1,2,3/NB,MO,W)   HEAT PIPE =MO
  1.00 (SLD) CORE L/D RATIO           (KVAPOR)  (1,2/LI,NA)  VAPOR     =NA
  10.0 (QAXL) AXIAL HT FLUX,KW/CM2    (IOPTN)  (1,2)         OPTION    =2
  200. (DTFMAX) MAX FUEL DELTA T,DEG K
  1.00 (HPL1) PIPE EXTENSION,M
 NOTE, OPTIONS ARE : 1-CODE PT DESIGN, 2-SPECIFIED DESIGN
  TYPE IN ANY OF FOLLOWING : DCORE(M) XREF(M) VNFT FBETA NPIPE ..STOP
NPIPE=210 STOP
                  210   (NPIPE) NO. OF HEAT PIPES
        BETA     VC      VCD     ALFA    PKAVG   BMIN    DXMIN  CORGAP ENDGAP
      0.500   0.005   0.050   0.600   1.500   0.050   0.080   0.015   0.005
  TYPE: STOP, OR NEW CONSTANTS IE. VC=0. PKAVG=2. ETC ...STOP
BETA=0.4 STOP
 SLD INDEX =     3
 VNF = 0.100 0.200 0.300 0.400 0.500 0.600 0.700 0.800 0.900 1.000
  DC = 0.196 0.208 0.230 0.260 0.299 0.352 0.437 0.585 0.943 *.
 DCH = 0.     0.     0.     0.     0.616 0.390 0.309 0.263 0.233 0.212
* * * * * * * * * * * * * * * TYPE GO OR START OVER * * * * * * * * * * * * * *
GO...ADJUST BETA FOR 10% SWELLING
 BETA =0.4000    VNF =0.6217    VF =0.3783    DX =0.1000    DC =0.3672
 REACTIVITY CHANGES, DELTA K
      BURN = 0.03113 EXP = 0.01764 SAFE = 0.02000 TOTAL = 0.06877
 FUEL ELEMENT VOLUME FRACTIONS
     CLADDING    FUEL REGION    HEAT PIPE    WALL+WICK     VAPOR
      0.0500       0.6336        0.3164        0.1265        0.1898
 HEXAGONAL CORNER CORRECTION FACTOR =1.1173
 NUMBER OF HEAT PIPES =     94.2127
   MINIMUM PRACTICAL (OR SPECIFIED) NUMBER OF HEAT PIPES =  210

 TEMPERATURE SUMMARY,DEGREE KELVIN
      MAXIMUM FUEL DELTA T =   89.7
      AVG DELTA T ACCROSS HEAT PIPE WALL =   11.4
      AVERAGE FUEL TEMPERATURE =1466.3
      MAXIMUM FUEL TEMPERATURE =1531.9
 BURN FRACTION OF U235 =0.0519
 FISSION DENSITY (FISSIONS/CM**3) = 7.630E+20
 FUEL SWELLING,VOLUME % =10.56
  "       "   , dense fuel % = 17.60
 REACTOR DIMENSIONS, METERS               FUEL ELEMENT DIMENSIONS, MM
   0.3672   CORE DIAMETER                     24.07   WIDTH ACCROSS HEX FLATS
   0.3672   CORE HEIGHT                       25.28   EQUIV. FUEL ELEMENT DIA
   0.5972   REACTOR DIAMETER                  24.64   EQUIV. FUEL REGION O.D.
   0.5772   REACTOR HEIGHT                    14.22   HEAT PIPE O.D.
   0.1000   REFLECTOR THICKNESS               11.01   VAPOR DIAMETER
   1.0000   PIPE LENGTH OUTSIDE REACTOR       95.26   VAPOR AREA, MM**2
   1.4722   TOTAL HEAT PIPE LENGTH
   1.5772   OVERALL REACTOR+HEAT PIPE LENGTH

 REACTOR WEIGHTS, KILOGRAMS
                 190.4   FUEL,  U235 MASS =  161.8
                 310.7   REFLECTOR
                 200.3   HEAT PIPES, WT/UNIT LENGTH (KG/M) = 136.03
                  33.0   CONTROL SYSTEM (ASSUME CONSTANT = 33 KG)
                  51.4   SUPPORT STRUCTURE (7% OF REACTOR WT)
               ---------
                 785.7   TOTAL REACTOR + HEAT PIPES

  81.56 MW/M**3,AVG POWR IN FUELSPACE     9.52 KW,POWER PER HEAT PIPE
  99.93 MW/M**2,HTPIPE AXIAL HT FLUX     0.750 MW/M**2,HTPIPE RAD HTFLX
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TYPE GO OR STOP

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                         ********************
 PROB NO. 19   5-17-78    TYPE NEW INPUT: PR=1, KHP=2 ...STOP
STOP

 4.000 (PR) REACTOR POWER,MW          (KCORE) (1,2/UC,UO2) CORE     =UC
 1425. (THP) HEAT PIPE TEMP,DEG K     (KREF) (1,2/BE,BEO)  REFLECTOR =BEO
 3650. (TIME) LIFETIME,DAYS           (KHP)(1,2,3/NB,MO,W) HEAT PIPE =MO
  1.00 (SLD) CORE L/D RATIO           (KVAPOR) (1,2/LI,NA) VAPOR     =NA
  10.0 (QAXL) AXIAL HT FLUX,KW/CM2 (IOPTN) (1,2)           OPTION    =2
  200. (DTFMAX) MAX FUEL DELTA T,DEG K
  1.00 (HPL1) PIPE EXTENSION,M
 NOTE, OPTIONS ARE : 1-CODE PT DESIGN, 2-SPECIFIED DESIGN
  TYPE IN ANY OF FOLLOWING : DCORE(M) XREF(M) VNFT BBETA NPIPE ..STOP
NPIPE=264 STOP
             264  (NPIPE) NO. OF HEAT PIPES
      BETA    VC     VCD    ALFA   PKAVG   BMIN   DXMIN  CORGAP ENDGAP
     0.600  0.004  0.050  0.600  1.500  0.050  0.080  0.015  0.005
  TYPE: STOP, OR NEW CONSTANTS IE. VC=0. PKAVG=2. ETC ...STOP
BETA=0.56 STOP
 SLD INDEX =      3
 VNF = 0.100 0.200 0.300 0.400 0.500 0.600 0.700 0.800 0.900 1.000
  DC = 0.196 0.208 0.230 0.260 0.299 0.352 0.437 0.585 0.943 *.
 DCH = 0.     0.     0.     0.     0.     1.512 0.567 0.416 0.344 0.300
* * * * * * * * * * * * * * * TYPE GO OR START OVER * * * * * * * * * * * * *
GO...ADJUST BETA FOR 10% SWELLING
 BETA =0.5600    VNF =0.7415    VF =0.2585    DX =0.1000    DC =0.4863
 REACTIVITY CHANGES, DELTA K
      BURN = 0.03924 EXP = 0.01764 SAFE = 0.02000 TOTAL = 0.07688
 FUEL ELEMENT VOLUME FRACTIONS
     CLADDING    FUEL REGION    HEAT PIPE    WALL+WICK    VAPOR
      0.0500       0.5898        0.3602       0.1441      0.2161
 HEXAGONAL CORNER CORRECTION FACTOR =1.1546
 NUMBER OF HEAT PIPES =   127.4595
   MINIMUM PRACTICAL (OR SPECIFIED) NUMBER OF HEAT PIPES =  264

 TEMPERATURE SUMMARY,DEGREE KELVIN
      MAXIMUM FUEL DELTA T =  96.6
      AVG DELTA T ACCROSS HEAT PIPE WALL =  13.7
      AVERAGE FUEL TEMPERATURE =1470.9
      MAXIMUM FUEL TEMPERATURE =1542.2
 BURN FRACTION OF U235 =0.0654
 FISSION DENSITY (FISSIONS/CM**3) = 7.054E+20
 FUEL SWELLING,VOLUME % =10.05
  "      "  , dense fuel % = 22.84
 REACTOR DIMENSIONS, METERS                FUEL ELEMENT DIMENSIONS, MM
   0.4863  CORE DIAMETER                     28.45  WIDTH ACCROSS HEX FLATS
   0.4863  CORE HEIGHT                       29.87  EQUIV. FUEL ELEMENT DIA
   0.7163  REACTOR DIAMETER                  29.11  EQUIV. FUEL REGION O.D.
   0.6963  REACTOR HEIGHT                    17.92  HEAT PIPE O.D.
   0.1000  REFLECTOR THICKNESS               13.88  VAPOR DIAMETER
   1.0000  PIPE LENGTH OUTSIDE REACTOR      151.40  VAPOR AREA, MM**2
   1.5913  TOTAL HEAT PIPE LENGTH
   1.6963  OVERALL REACTOR+HEAT PIPE LENGTH

 REACTOR WEIGHTS, KILOGRAMS
               302.0  FUEL,  U235 MASS =  256.7
               493.6  REFLECTOR
               432.5  HEAT PIPES, WT/UNIT LENGTH (KG/M) = 271.80
                33.0  CONTROL SYSTEM (ASSUME CONSTANT = 33 KG
                88.3  SUPPORT STRUCTURE (7% OF REACTOR WT)
             ---------
              1349.4  TOTAL REACTOR + HEAT PIPES

  75.40 MW/M**3,AVG POWR IN FUELSPACE   15.15 KW,POWER PER HEAT PIPE
 100.03 MW/M**2,HTPIPE AXIAL HT FLUX    0.714 MW/M**2,HTPIPE RAD HTFLX
                         ********************
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GO
                    ********************
 PROB NO.  1   5-18-78    TYPE NEW INPUT! PR=1, KHP=2 ...STOP
PR=0.2 THP=1425. TIME=3650. KCORE=5 KREF=2 IOPTN=2 STOP

 0.200 (PR) REACTOR POWER,MW          (KCORE) (1,2/UC,UO2) CORE   =MO60UO2
 1425. (THP) HEAT PIPE TEMP,DEG K     (KREF)  (1,2/BE,BEO)  REFLECTOR =BEO
 3650. (TIME) LIFETIME,DAYS           (KHP)(1,2,3/NB,MO,W) HEAT PIPE =MO
  1.00 (SLD) CORE L/D RATIO           (KVAPOR) (1,2/LI,NA) VAPOR     =NA
  10.0 (QAXL) AXIAL HT FLUX,KW/CM2 (IOPTN) (1,2)           OPTION    =2
  200. (DTFMAX) MAX FUEL DELTA T,DEG K
  1.00 (HEL1) PIPE EXTENSION,M
 NOTE, OPTIONS ARE : 1-CODE PT DESIGN, 2-SPECIFIED DESIGN
  TYPE IN ANY OF FOLLOWING : DCORE(M) XREF(M) VNFT FBETA NPIPE ..STOP
NPIPE=84 STOP
                 84   (NPIPE) NO. OF HEAT PIPES
       BETA    VC      VCD    ALFA    PKAVG   BMIN    DXMIN CORGAP ENDGAP
    0.100  0.      0.050  0.600  1.500  0.050  0.030  0.015  0.005
  TYPE: STOP, OR NEW CONSTANTS IE. VC=0. PKAVG=2. ETC ...STOP
VC=0.012 VCD=0. STOP
 SLD INDEX =     3
 VNF = 0.100 0.200 0.300 0.400 0.500 0.600 0.700 0.800 0.900 1.000
  DC = 0.299 0.326 0.363 0.412 0.475 0.562 0.694 0.961 1.754 *.
 DCH = 0.      0.207 0.142 0.115 0.099 0.088 0.081 0.074 0.070 0.066
* * * * * * * * * * * * * * * TYPE GO OR START OVER * * * * * * * * * * * * * *
GO
 BETA =0.1000    VNF =0.1501    VF =0.8499    DX =0.1000    DC =0.3115
 REACTIVITY CHANGES, DELTA K
      BURN = 0.00464 EXP = 0.01274 SAFE = 0.02000 TOTAL = 0.03738
 FUEL ELEMENT VOLUME FRACTIONS
     CLADDING    FUEL REGION    HEAT PIPE    WALL+WICK    VAPOR
     0.           0.9558       0.0442       0.0177       0.0265
 HEXAGONAL CORNER CORRECTION FACTOR =1.0020
 NUMBER OF HEAT PIPES =    31.5836
   MINIMUM PRACTICAL (OR SPECIFIED) NUMBER OF HEAT PIPES =    84

 TEMPERATURE SUMMARY,DEGREE KELVIN
      MAXIMUM FUEL DELTA T =  75.2
      AVG DELTA T ACCROSS HEAT PIPE WALL =    3.4
      AVERAGE FUEL TEMPERATURE =1453.4
      MAXIMUM FUEL TEMPERATURE =1505.3
 BURN FRACTION OF U235 =0.0077
 FISSION DENSITY (FISSIONS/CM**3) = 8.345E+19
 FUEL SWELLING,VOLUME % = 0.

 REACTOR DIMENSIONS, METERS               FUEL ELEMENT DIMENSIONS, MM
   0.3115  CORE DIAMETER                     32.18  WIDTH ACCROSS HEX FLATS
   0.3115  CORE HEIGHT                       33.79  EQUIV. FUEL ELEMENT DIA
   0.5415  REACTOR DIAMETER                  33.79  EQUIV. FUEL REGION O.D.
   0.5215  REACTOR HEIGHT                     7.11  HEAT PIPE O.D.
   0.1000  REFLECTOR THICKNESS                5.51  VAPOR DIAMETER
   1.0000  PIPE LENGTH OUTSIDE REACTOR       23.80  VAPOR AREA, MM**2
   1.4165  TOTAL HEAT PIPE LENGTH
   1.5215  OVERALL REACTOR+HEAT PIPE LENGTH

 REACTOR WEIGHTS, KILOGRAMS
              214.3  FUEL,  U235 MASS =   108.7
              240.2  REFLECTOR
               19.3  HEAT PIPES, WT/UNIT LENGTH (KG/M) =  13.60
               33.0  CONTROL SYSTEM (ASSUME CONSTANT = 33 KG)
               35.5  SUPPORT STRUCTURE (7% OF REACTOR WT)
           ---------
              542.2  TOTAL REACTOR + HEAT PIPES

   8.92 MW/M**3,AVG POWR IN FUELSPACE    2.38 KW,POWER PER HEAT PIPE
 100.04 MW/M**2,HTPIPE AXIAL HT FLUX    0.442 MW/M**2,HTPIPE RAD HTFLX
                    ********************
      TYPE GO OR STOP
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PROJ NO.  2    5-18-78    TYPE NEW INPUT! PR=1, KHP=2 ...STOP
PR=0.4 STOP

 0.400 (PR) REACTOR POWER,MW          (KCORE) (1,2/UC,UO2) CORE     =NO60UO2
 1425. (THP) HEAT PIPE TEMP,DEG K     (KREF) (1,2/BE,BEO)  REFLECTOR =BEO
 3650. (TIME) LIFETIME,DAYS           (KHP)(1,2,3/NB,MO,W) HEAT PIPE =MO
  1.00 (SLD) CORE L/D RATIO           (KVAPOR) (1,2/LI,NA) VAPOR     =NA
  10.0 (DAXL) AXIAL HT FLUX,KW/CM2 (IOPTN) (1,2)           OPTION    =2
  200. (DTFMAX) MAX FUEL DELTA T,DEG K
  1.00 (HPL1) PIPE EXTENSION,M
 NOTE, OPTIONS ARE ! 1-CODE PT DESIGN, 2-SPECIFIED DESIGN
  TYPE IN ANY OF FOLLOWING ! DCORE(M) XREF(M) VNFT FSETA NPIPE ..STOP
NPIPE=84 STOP
                  84   (NPIPE) NO. OF HEAT PIPES
        SETA    VC      VCD     ALFA    PKAVG   SMIN    DXMIN CORGAP ENDGAP
      0.100  0.012  0.       0.600  1.500  0.050  0.080  0.015  0.005
  TYPE! STOP, OR NEW CONSTANTS IE. VC=0. PKAVG=2. ETC ...STOP
STOP
 SLD INDEX =      3
 VNF = 0.100 0.200 0.300 0.400 0.500 0.600 0.700 0.800 0.900 1.000
  DC = 0.299 0.326 0.363 0.412 0.475 0.562 0.694 0.961 1.754 *.
 DCH = 0.     0.293 0.201 0.163 0.140 0.125 0.114 0.105 0.098 0.093
* * * * * * * * * * * * * TYPE GO OR START OVER * * * * * * * * * * * * *
GO
 SETA =0.1000    VNF =0.1848    VF =0.8152    DX =0.1000    DC =0.3214
 REACTIVITY CHANGES, DELTA K
      BURN = 0.00881 EXP = 0.01274 SAFE = 0.02000 TOTAL = 0.04155
 FUEL ELEMENT VOLUME FRACTIONS
     CLADDING    FUEL REGION    HEAT PIPE    WALL+WICK    VAPOR
      0.          0.9167        0.0833        0.0333       0.0500
 HEXAGONAL CORNER CORRECTION FACTOR =1.0070
 NUMBER OF HEAT PIPES =    46.5570
   MINIMUM PRACTICAL (OR SPECIFIED) NUMBER OF HEAT PIPES =    84

 TEMPERATURE SUMMARY,DEGREE KELVIN
      MAXIMUM FUEL DELTA T = 110.8
      AVG DELTA T ACCROSS HEAT PIPE WALL =    6.5
      AVERAGE FUEL TEMPERATURE =1468.5
      MAXIMUM FUEL TEMPERATURE =1545.7
 BURN FRACTION OF U235 =0.0147
 FISSION DENSITY (FISSIONS/CM**3) = 1.585E+20
 FUEL SWELLING,VOLUME % = 0.

 REACTOR DIMENSIONS, METERS              FUEL ELEMENT DIMENSIONS, MM
   0.3214   CORE DIAMETER                    33.19   WIDTH ACCROSS HEX FLATS
   0.3214   CORE HEIGHT                      34.85   EQUIV. FUEL ELEMENT DIA
   0.5514   REACTOR DIAMETER                 34.85   EQUIV. FUEL REGION O.D.
   0.5314   REACTOR HEIGHT                   10.06   HEAT PIPE O.D.
   0.1000   REFLECTOR THICKNESS               7.79   VAPOR DIAMETER
   1.0000   PIPE LENGTH OUTSIDE REACTOR      47.66   VAPOR AREA, MM**2
   1.4264   TOTAL HEAT PIPE LENGTH
   1.5314   OVERALL REACTOR+HEAT PIPE LENGTH

 REACTOR WEIGHTS, KILOGRAMS
                 225.6   FUEL,  U235 MASS =  114.4
                 251.9   REFLECTOR
                  38.8   HEAT PIPES, WT/UNIT LENGTH (KG/M) =  27.22
                  33.0   CONTROL SYSTEM (ASSUME CONSTANT = 33 KG)
                  38.5   SUPPORT STRUCTURE (7% OF REACTOR WT)
              ---------
                 587.9   TOTAL REACTOR + HEAT PIPES

  16.94 MW/M**3,AVG POWR IN FUELSPACE    4.76 KW,POWER PER HEAT PIPE
  99.92 MW/M**2,HTPIPE AXIAL HT FLUX    0.605 MW/M**2,HTPIPE RAD HTFLX
                         ********************

      TYPE GO OR STOP
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GO
                        ********************
 PROB NO.   3   5-18-78    TYPE NEW INPUT! PR=1. KHP=2 ...STOP
PR=0.7 STOP

 0.700 (PR) REACTOR POWER,MW          (KCORE) (1,2/UC,UO2) CORE   =MO60UO2
 1425.  (THP) HEAT PIPE TEMP,DEG K    (KREF)  (1,2/BE,BEO)  REFLECTOR =BEO
 3650.  (TIME) LIFETIME,DAYS          (KHP)(1,2,3/NB,MO,W) HEAT PIPE =MO
  1.00 (RLD) CORE L/D RATIO           (KVAPOR) (1,2/LI,NA) VAPOR     =NA
  10.0 (QAXL) AXIAL HT FLUX,KW/CM2 (IOPTN) (1,2)          OPTION    =2
  200.  (DTFMAX) MAX FUEL DELTA T,DEG K
  1.00 (HPL1) PIPE EXTENSION,M
 NOTE, OPTIONS ARE ! 1-CODE PT DESIGN, 2-SPECIFIED DESIGN
  TYPE IN ANY OF FOLLOWING ! DCORE(M) XREF(M) VNFT RBETA NPIPE ..STOP
NPIPE=120 STOP
              120  (NPIPE) NO. OF HEAT PIPES
        BETA    VC      VCD     ALFA    PKAVG   BMIN   DXMIN CORGAP ENDGAP
     0.100  0.012  0.       0.600  1.500  0.050  0.080  0.015  0.005
  TYPE! STOP, OR NEW CONSTANTS IE. VC=0. PKAVG=2. ETC ...STOP
VC=0.008 STOP
 RLD INDEX =      3
 VNF = 0.100 0.200 0.300 0.400 0.500 0.600 0.700 0.800 0.900 1.000
  DC = 0.299 0.326 0.363 0.412 0.475 0.562 0.694 0.961 1.754 *.
 DCH = 0.     0.380 0.263 0.214 0.184 0.165 0.150 0.139 0.130 0.122
* * * * * * * * * * * * * * TYPE GO OR START OVER * * * * * * * * * * * * * *
GO
 BETA =0.1000    VNF =0.2264    VF =0.7736    DX =0.1000    DC =0.3348
 REACTIVITY CHANGES, DELTA K
      BURN = 0.01435 EXP = 0.01274 SAFE = 0.02000 TOTAL = 0.04709
 FUEL ELEMENT VOLUME FRACTIONS
     CLADDING    FUEL REGION    HEAT PIPE    WALL+WICK    VAPOR
    0.           0.8665        0.1335       0.0534       0.0801
 HEXAGONAL CORNER CORRECTION FACTOR =1.0180
 NUMBER OF HEAT PIPES =    61.1476
   MINIMUM PRACTICAL (OR SPECIFIED) NUMBER OF HEAT PIPES =  120

 TEMPERATURE SUMMARY,DEGREE KELVIN
      MAXIMUM FUEL DELTA T = 101.9
      AVG DELTA T ACCROSS HEAT PIPE WALL =   7.7
      AVERAGE FUEL TEMPERATURE =1466.7
      MAXIMUM FUEL TEMPERATURE =1538.4
 BURN FRACTION OF U235 =0.0239
 FISSION DENSITY (FISSIONS/CM**3) = 2.584E+20
 FUEL SWELLING,VOLUME % = 0.

 REACTOR DIMENSIONS, METERS            FUEL ELEMENT DIMENSIONS, MM
   0.3348  CORE DIAMETER                    29.00  WIDTH ACCROSS HEX FLATS
   0.3348  CORE HEIGHT                      30.44  EQUIV. FUEL ELEMENT DIA
   0.5648  REACTOR DIAMETER                 30.44  EQUIV. FUEL REGION O.D.
   0.5448  REACTOR HEIGHT                   11.12  HEAT PIPE O.D.
   0.1000  REFLECTOR THICKNESS               8.62  VAPOR DIAMETER
   1.0000  PIPE LENGTH OUTSIDE REACTOR      58.31  VAPOR AREA, MM**2
   1.4398  TOTAL HEAT PIPE LENGTH
   1.5448  OVERALL REACTOR+HEAT PIPE LENGTH

 REACTOR WEIGHTS, KILOGRAMS
              242.3  FUEL,  U235 MASS =  122.8
              263.5  REFLECTOR
               68.5  HEAT PIPES, WT/UNIT LENGTH (KG/M) =  47.58
               33.0  CONTROL SYSTEM (ASSUME CONSTANT = 33 KG)
               42.9  SUPPORT STRUCTURE (7% OF REACTOR WT)
          ----------
              655.2  TOTAL REACTOR + HEAT PIPES

  27.62 MW/M**3,AVG POWR IN FUELSPACE    5.83 KW,POWER PER HEAT PIPE
 100.05 MW/M**2,HTPIPE AXIAL HT FLUX   0.644 MW/M**2,HTPIPE RAD HTFLX
                        ********************
      TYPE GO OR STOP
```

GO

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PROB NO.  4   5-18-78    TYPE NEW INPUT! PR=1. KHP=2 ...STOP
PR=1. STOP

 1.000 (PR) REACTOR POWER,MW          (KCORE) (1,2/UC,UO2) CORE  =MO60UO2
 1425. (THP) HEAT PIPE TEMP,DEG K     (KREF) (1,2/BE,BEO)  REFLECTOR =BEO
 3650. (TIME) LIFETIME,DAYS           (KHP)(1,2,3/NB,MO,W) HEAT PIPE =MO
  1.00 (SLD) CORE L/D RATIO           (KVAPOR) (1,2/LI,NA) VAPOR     =NA
  10.0 (QAXL) AXIAL HT FLUX,KW/CM2 (IOPTN) (1,2)           OPTION    =2
  200. (DTFMAX) MAX FUEL DELTA T,DEG K
  1.00 (HPL1) PIPE EXTENSION,M
 NOTE, OPTIONS ARE : 1-CODE PT DESIGN, 2-SPECIFIED DESIGN
  TYPE IN ANY OF FOLLOWING : DCORE(M) XREF(M) VNFT FBETA NPIPE ..STOP
NPIPE=162 STOP
                162  (NPIPE) NO. OF HEAT PIPES
        BETA    VC      VCD     ALFA    PKAVG   BMIN    DXMIN  CORSAF ENDGAP
       0.100  0.008  0.       0.600  1.500  0.050  0.080  0.015  0.005
 TYPE: STOP, OR NEW CONSTANTS IE. VC=0. PKAVG=2. ETC ...STOP
VC=0.006 STOP
 SLD INDEX =     3
 VNF = 0.100 0.200 0.300 0.400 0.500 0.600 0.700 0.800 0.900 1.000
  DC = 0.299 0.326 0.363 0.412 0.475 0.562 0.694 0.961 1.754 +.
 DCH = 0.    0.449 0.313 0.255 0.220 0.197 0.179 0.166 0.155 0.146
◆ ◆ ◆ ◆ ◆ ◆ ◆ ◆ ◆ ◆ ◆ ◆ TYPE GO OR START OVER ◆ ◆ ◆ ◆ ◆ ◆ ◆ ◆ ◆ ◆ ◆ ◆
GO
 BETA =0.1000    VNF =0.2630    VF =0.7370    DX =0.1000    DC =0.3482
 REACTIVITY CHANGES, DELTA K
      BURN = 0.01915 EXP = 0.01274 SAFE = 0.02000 TOTAL = 0.05189
 FUEL ELEMENT VOLUME FRACTIONS
     CLADDING   FUEL REGION   HEAT PIPE   WALL+WICK   VAPOR
      0.           0.8238       0.1762      0.0705      0.1057
 HEXAGONAL CORNER CORRECTION FACTOR =1.0315
 NUMBER OF HEAT PIPES =    71.2219
   MINIMUM PRACTICAL (OR SPECIFIED) NUMBER OF HEAT PIPES =  162

 TEMPERATURE SUMMARY,DEGREE KELVIN
      MAXIMUM FUEL DELTA T =  87.9
      AVG DELTA T ACCROSS HEAT PIPE WALL =   7.8
      AVERAGE FUEL TEMPERATURE =1462.1
      MAXIMUM FUEL TEMPERATURE =1524.7
 BURN FRACTION OF U235 =0.0319
 FISSION DENSITY (FISSIONS/CM**3) = 3.447E+20
 FUEL SWELLING,VOLUME % = 0.

 REACTOR DIMENSIONS, METERS               FUEL ELEMENT DIMENSIONS, MM
   0.3482  CORE DIAMETER                       25.97  WIDTH ACCROSS HEX FLATS
   0.3482  CORE HEIGHT                         27.27  EQUIV. FUEL ELEMENT DIA
   0.5782  REACTOR DIAMETER                    27.27  EQUIV. FUEL REGION O.D.
   0.5582  REACTOR HEIGHT                      11.45  HEAT PIPE O.D.
   0.1000  REFLECTOR THICKNESS                  8.87  VAPOR DIAMETER
   1.0000  PIPE LENGTH OUTSIDE REACTOR         61.74  VAPOR AREA, MM**2
   1.4532  TOTAL HEAT PIPE LENGTH
   1.5582  OVERALL REACTOR+HEAT PIPE LENGTH

 REACTOR WEIGHTS, KILOGRAMS
             259.4  FUEL,  U235 MASS =  131.5
             285.5  REFLECTOR
              98.8  HEAT PIPES, WT/UNIT LENGTH (KG/M) =  68.02
              33.0  CONTROL SYSTEM (ASSUME CONSTANT = 33 KG)
              47.4  SUPPORT STRUCTURE (7% OF REACTOR WT)
          ---------
             724.1  TOTAL REACTOR + HEAT PIPES

  36.84 MW/M**3,AVG POWR IN FUELSPACE    6.17 KW,POWER PER HEAT PIPE
  99.98 MW/M**2,HTPIPE AXIAL HT FLUX    0.637 MW/M**2,HTPIPE RAD HTFLX
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TYPE GO OR STOP

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GO
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 PROB NO.  5   5-18-78     TYPE NEW INPUT: PR=1, KHP=2 ...STOP
PR=2, STOP

 2.000 (PR) REACTOR POWER,MW          (KCORE) (1,2/UC,UO2) CORE   =MO60UO2
 1425.  (THP) HEAT PIPE TEMP,DEG K    (KREF)  (1,2/BE,BEO)  REFLECTOR =BEO
 3650.  (TIME) LIFETIME,DAYS          (KHP)(1,2,3/NB,MO,W) HEAT PIPE =MO
  1.00 (SLD) CORE L/D RATIO           (KVAPOR)  (1,2/LI,NA) VAPOR     =NA
  10.0 (DAXL) AXIAL HT FLUX,KW/CM2 (IOPTN)  (1,2)           OPTION    =2
  200. (DTFMAX) MAX FUEL DELTA T,DEG K
  1.00 (HPL1) PIPE EXTENSION,M
 NOTE, OPTIONS ARE : 1-CODE PT DESIGN, 2-SPECIFIED DESIGN
  TYPE IN ANY OF FOLLOWING : DCORE(M) XREF(M) VNFT FBETA NPIPE ..STOP
NPIPE=210 STOP
               210   (NPIPE) NO. OF HEAT PIPES
        BETA    VC      VCD     ALFA    PKAVG   BMIN    DXMIN  CORGAP ENDGAP
     0.100  0.006   0.       0.600  1.500  0.050  0.080  0.015  0.005
  TYPE: STOP, OR NEW CONSTANTS IE. VC=0. PKAVG=2. ETC ...STOP
VC=0.005 STOP
 SLD INDEX =     3
 VNF = 0.100 0.200 0.300 0.400 0.500 0.600 0.700 0.800 0.900 1.000
  DC = 0.299 0.326 0.363 0.412 0.475 0.562 0.694 0.961 1.754 *.
 DCH = 0.     0.632 0.442 0.360 0.311 0.278 0.253 0.234 0.219 0.207
* * * * * * * * * * * * * TYPE GO OR START OVER * * * * * * * * * * * * * *
GO
 BETA =0.1000   VNF =0.3566    VF =0.6434    DX =0.1000    DC =0.3893
 REACTIVITY CHANGES, DELTA K
      BURN = 0.03138 EXP = 0.01274 SAFE = 0.02000 TOTAL = 0.06412
 FUEL ELEMENT VOLUME FRACTIONS
     CLADDING    FUEL REGION    HEAT PIPE    WALL+WICK    VAPOR
      0.          0.7185        0.2815       0.1126       0.1689
 HEXAGONAL CORNER CORRECTION FACTOR =1.0325
 NUMBER OF HEAT PIPES =    92.2398
   MINIMUM PRACTICAL (OR SPECIFIED) NUMBER OF HEAT PIPES =  210

 TEMPERATURE SUMMARY,DEGREE KELVIN
      MAXIMUM FUEL DELTA T =   87.8
      AVG DELTA T ACCROSS HEAT PIPE WALL =   10.8
      AVERAGE FUEL TEMPERATURE =1465.1
      MAXIMUM FUEL TEMPERATURE =1529.0
 BURN FRACTION OF U235 =0.0523
 FISSION DENSITY (FISSIONS/CM**3) = 5.648E+20
 FUEL SWELLING,VOLUME % = 0.

 REACTOR DIMENSIONS, METERS            FUEL ELEMENT DIMENSIONS, MM
   0.3893  CORE DIAMETER                     25.52  WIDTH ACCROSS HEX FLATS
   0.3893  CORE HEIGHT                       26.80  EQUIV. FUEL ELEMENT DIA
   0.6193  REACTOR DIAMETER                  26.80  EQUIV. FUEL REGION O.D.
   0.5993  REACTOR HEIGHT                    14.22  HEAT PIPE O.D.
   0.1000  REFLECTOR THICKNESS               11.01  VAPOR DIAMETER
   1.0000  PIPE LENGTH OUTSIDE REACTOR       95.26  VAPOR AREA, MM**2
   1.4943  TOTAL HEAT PIPE LENGTH
   1.5993  OVERALL REACTOR+HEAT PIPE LENGTH

 REACTOR WEIGHTS, KILOGRAMS
               316.6  FUEL,  U235 MASS =  160.5
               341.3  REFLECTOR
               203.3  HEAT PIPES, WT/UNIT LENGTH (KG/M) = 136.03
                33.0  CONTROL SYSTEM (ASSUME CONSTANT = 33 KG)
                62.6  SUPPORT STRUCTURE (7% OF REACTOR WT)
          ---------------
               956.7  TOTAL REACTOR + HEAT PIPES

  60.37 MW/M**3,AVG POWR IN FUELSPACE   9.52 KW,POWER PER HEAT PIPE
  99.98 MW/M**2,HTPIPE AXIAL HT FLUX    0.707 MW/M**2,HTPIPE RAD HTFLX
                        *********************
      TYPE GO OR STOP
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GO
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 PROF NO.  5   5-18-78    TYPE NEW INPUT: PR=1. KHP=2 ...STOP
PR=4. STOP

 4.000 (PR) REACTOR POWER,MW          (KCORE) (1,2/UC,UO2) CORE    =MO50UO2
 1425. (THP) HEAT PIPE TEMP,DEG K     (KREF) (1,2/B   EO)   REFLECTOR =BEO
 3650. (TIME) LIFETIME,DAYS           (KHP)(1,2,3/N     W) HEAT PIPE =MO
  1.00 (SLD) CORE L/D RATIO           (KVAPOR) (1,2/LI, A) VAPOR     =NA
  10.0 (DAXL) AXIAL HT FLUX,KW/CM2 (IOPTN) (1,2)             OPTION    =2
  200. (DTFMAX) MAX FUEL DELTA T,DEG K
  1.00 (HPL1) PIPE EXTENSION,M
 NOTE, OPTIONS ARE : 1-CODE PT DESIGN, 2-SPECIFIED DESIGN
  TYPE IN ANY OF FOLLOWING : DCORE(M) XREF(M) VNFT BBETA NPIPE ..STOP
NPIPE=266 STOP
                   266   (NPIPE) NO. OF HEAT PIPES
       BETA    VC      VCD     ALFA    PKAVG   EMIN    DXMIN  CORGAP ENDGAP
     0.100   0.004   0.      0.600   1.500   0.050   0.080   0.015   0.005
  TYPE: STOP, OR NEW CONSTANTS IE. VC=0. PKAVG=2. ETC ...STOP
STOP
 SLD INDEX =     3
 VNF = 0.100 0.200 0.300 0.400 0.500 0.600 0.700 0.800 0.900 1.000
  DC = 0.299 0.326 0.363 0.412 0.475 0.562 0.694 0.961 1.754 *.
 DCH = 0.    0.890 0.624 0.508 0.439 0.392 0.358 0.331 0.310 0.292
* * * * * * * * * * * * * TYPE GO OR START OVER * * * * * * * * * * * *
GO
 BETA =0.1000    VNF =0.4720    VF =0.5280    DX =0.1000    DC =0.4554
 REACTIVITY CHANGES, DELTA K
      BURN = 0.04777 EXP = 0.01274 SAFE = 0.02000 TOTAL = 0.08051
 FUEL ELEMENT VOLUME FRACTIONS
     CLADDING    FUEL REGION    HEAT PIPE    WALL+WICK    VAPOR
      0.           0.5890        0.4110        0.1644      0.2466
 HEXAGONAL CORNER CORRECTION FACTOR =1.1840
 NUMBER OF HEAT PIPES =  115.0234
   MINIMUM PRACTICAL (OR SPECIFIED) NUMBER OF HEAT PIPES =  266

 TEMPERATURE SUMMARY,DEGREE KELVIN
      MAXIMUM FUEL DELTA T =  86.5
      AVG DELTA T ACCROSS HEAT PIPE WALL =  14.6
      AVERAGE FUEL TEMPERATURE =1468.4
      MAXIMUM FUEL TEMPERATURE =1533.3
 BURN FRACTION OF U235 =0.0796
 FISSION DENSITY (FISSIONS/CM**3) = 8.599E+20
 FUEL SWELLING,VOLUME % = 0.

 REACTOR DIMENSIONS, METERS              FUEL ELEMENT DIMENSIONS, MM
   0.4554  CORE DIAMETER                    26.54  WIDTH ACCROSS HEX FLATS
   0.4554  CORE HEIGHT                      27.87  EQUIV. FUEL ELEMENT DIA
   0.6854  REACTOR DIAMETER                 27.87  EQUIV. FUEL REGION O.D.
   0.6654  REACTOR HEIGHT                   17.87  HEAT PIPE O.D.
   0.1000  REFLECTOR THICKNESS              13.84  VAPOR DIAMETER
   1.0000  PIPE LENGTH OUTSIDE REACTOR     150.41  VAPOR AREA, MM**2
   1.5604  TOTAL HEAT PIPE LENGTH
   1.6654  OVERALL REACTOR+HEAT PIPE LENGTH

 REACTOR WEIGHTS, KILOGRAMS
               416.0  FUEL,  U235 MASS =  210.9
               442.0  REFLECTOR
               424.5  HEAT PIPES, WT/UNIT LENGTH (KG/M) = 272.05
                33.0  CONTROL SYSTEM (ASSUME CONSTANT = 33 KG)
                92.1  SUPPORT STRUCTURE (7% OF REACTOR WT)
             ----------
              1407.5  TOTAL REACTOR + HEAT PIPES

  91.91 MW/M**3,AVG POWR IN FUELSPACE  15.04 KW,POWER PER HEAT PIPE
  99.99 MW/M**2,HTPIPE AXIAL HT FLUX    0.760 MW/M**2,HTPIPE RAD HTFLX
                       ********************
      TYPE GO OR STOP
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 PROB NO.   9   5-18-78     TYPE NEW INPUT! PR=1. KHP=2 ...STOP
PR=0.2 THP=1600. KVAPOR=1 STOP

 0.200  (PR) REACTOR POWER,MW           (KCORE)  (1,2/UC,UO2)  CORE    =MO60UO2
 1600.  (THP) HEAT PIPE TEMP,DEG K      (KREF)  (1,2/BE,BEO)   REFLECTOR =BEO
 3650.  (TIME) LIFETIME,DAYS            (KHP) (1,2,3/NB,MO,W)  HEAT PIPE =MO
  1.00  (FLD) CORE L/D RATIO            (KVAPOR)  (1,2/LI,NA)  VAPOR      =LI
  10.0  (QAXL) AXIAL HT FLUX,KW/CM2  (IOPTN)  (1,2)            OPTION     =2
  200.  (DTFMAX) MAX FUEL DELTA T,DEG K
  1.00  (HPL1) PIPE EXTENSION,M
 NOTE, OPTIONS ARE : 1-CODE PT DESIGN, 2-SPECIFIED DESIGN
  TYPE IN ANY OF FOLLOWING : DCORE(M) XREF(M) VNFT FBETA NPIPE ..STOP
NPIPE=84 STOP
                    84   (NPIPE) NO. OF HEAT PIPES
        BETA     VC       VCD      ALFA     PKAVG    BMIN    DXMIN  CORGAP ENDGAP
      0.100   0.004   0.        0.600   1.500   0.050   0.030   0.015   0.005
  TYPE: STOP, OR NEW CONSTANTS IE. VC=0. PKAVG=2. ETC ...STOP
VC=0.012 STOP
 SLD INDEX =     3
 VNF = 0.100 0.200 0.300 0.400 0.500 0.600 0.700 0.800 0.900 1.000
  DC = 0.299 0.326 0.363 0.412 0.475 0.562 0.694 0.961 1.754 *.
 DCH = 0.     0.207 0.142 0.115 0.099 0.088 0.081 0.074 0.070 0.066
* * * * * * * * * * * * TYPE GO OR START OVER * * * * * * * * * * * *
GO
 BETA =0.1000   VNF =0.1501   VF =0.8499    DX =0.1000   DC =0.3115
 REACTIVITY CHANGES, DELTA K
      BURN = 0.00464 EXP = 0.01456 SAFE = 0.02000 TOTAL = 0.03920
 FUEL ELEMENT VOLUME FRACTIONS
     CLADDING    FUEL REGION    HEAT PIPE    WALL+WICK     VAPOR
      0.            0.9558       0.0442       0.0177        0.0265
 HEXAGONAL CORNER CORRECTION FACTOR =1.0020
 NUMBER OF HEAT PIPES =    31.5836
   MINIMUM PRACTICAL (OR SPECIFIED) NUMBER OF HEAT PIPES =    84

 TEMPERATURE SUMMARY,DEGREE KELVIN
      MAXIMUM FUEL DELTA T =  75.2
      AVG DELTA T ACCROSS HEAT PIPE WALL =    3.4
      AVERAGE FUEL TEMPERATURE =1628.4
      MAXIMUM FUEL TEMPERATURE =1680.3
 BURN FRACTION OF U235 =0.0077
 FISSION DENSITY (FISSIONS/CM**3) = 8.345E+19
 FUEL SWELLING,VOLUME % = 0.

 REACTOR DIMENSIONS, METERS              FUEL ELEMENT DIMENSIONS, MM
   0.3115   CORE DIAMETER                         32.18   WIDTH ACCROSS HEX FLATS
   0.3115   CORE HEIGHT                           33.79   EQUIV. FUEL ELEMENT DIA
   0.5415   REACTOR DIAMETER                      33.79   EQUIV. FUEL REGION O.D.
   0.5215   REACTOR HEIGHT                         7.11   HEAT PIPE O.D.
   0.1000   REFLECTOR THICKNESS                    5.51   VAPOR DIAMETER
   1.0000   PIPE LENGTH OUTSIDE REACTOR           23.80   VAPOR AREA, MM**2
   1.4165   TOTAL HEAT PIPE LENGTH
   1.5215   OVERALL REACTOR+HEAT PIPE LENGTH

 REACTOR WEIGHTS, KILOGRAMS
                 214.3   FUEL,   U235 MASS =  108.7
                 240.2   REFLECTOR
                  19.3   HEAT PIPES, WT/UNIT LENGTH (KG/M) =  13.60
                  33.0   CONTROL SYSTEM (ASSUME CONSTANT = 33 KG)
                  35.5   SUPPORT STRUCTURE (7% OF REACTOR WT)
              ---------
                 542.2   TOTAL REACTOR + HEAT PIPES

   8.99 MW/M**3,AVG POWR IN FUELSPACE    2.38 KW,POWER PER HEAT PIPE
 100.04 MW/M**2,HTPIPE AXIAL HT FLUX    0.442 MW/M**2,HTPIPE RAD HTFLX
                              *********************
       TYPE GO OR STOP
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GO
                              *********************
PROB NO. 10    5-18-78     TYPE NEW INPUT: PR=1. KHP=2 ...STOP
PR=0.4 STOP

 0.400 (PR) REACTOR POWER,MW          (KCORE) (1,2/UC,UO2) CORE   =MO60UO2
 1600. (THP) HEAT PIPE TEMP,DEG K     (KREF) (1,2/BE,BEO)  REFLECTOR =BEO
 3650. (TIME) LIFETIME,DAYS           (KHP) (1,2,3/NB,MO,W) HEAT PIPE =MO
  1.00 (FLD) CORE L/D RATIO           (KVAPOR) (1,2/LI,NA) VAPOR     =LI
  10.0 (DAXL) AXIAL HT FLUX,KW/CM2    (IOPTN) (1,2)         OPTION    =2
  200. (DTFMAX) MAX FUEL DELTA T,DEG K
  1.00 (HPL1) PIPE EXTENSION,M
 NOTE, OPTIONS ARE : 1-CODE PT DESIGN, 2-SPECIFIED DESIGN
  TYPE IN ANY OF FOLLOWING : DCORE(M) XREF(M) VNFT FBETA NPIPE ..STOP
NPIPE=84 STOP
                   84   (NPIPE) NO. OF HEAT PIPES
         BETA    VC      VCD     ALFA    PKAVG   BMIN    DXMIN CORGAP ENDGAP
      0.100   0.012   0.       0.600   1.500   0.050   0.080  0.015  0.005
  TYPE: STOP, OR NEW CONSTANTS IE. VC=0. PKAVG=2. ETC ...STOP
STOP
 FLD INDEX =     3
 VNF = 0.100 0.200 0.300 0.400 0.500 0.600 0.700 0.800 0.900 1.000
  DC = 0.239 0.326 0.363 0.412 0.475 0.562 0.694 0.961 1.754 *.
 DCH = 0.     0.293 0.201 0.163 0.140 0.125 0.114 0.105 0.098 0.093
* * * * * * * * * * * * * * TYPE GO OR START OVER * * * * * * * * * * * * * *
GO
 BETA =0.1000    VNF =0.1843    VF =0.8152    DX =0.1000    DC =0.3214
 REACTIVITY CHANGES, DELTA K
      BURN = 0.00881 EXP = 0.01456 SAFE = 0.02000 TOTAL = 0.04337
 FUEL ELEMENT VOLUME FRACTIONS
     CLADDING    FUEL REGION    HEAT PIPE    WALL+WICK    VAPOR
     0.             0.9167        0.0833       0.0333       0.0500
 HEXAGONAL CORNER CORRECTION FACTOR =1.0070
 NUMBER OF HEAT PIPES =    46.5570
   MINIMUM PRACTICAL (OR SPECIFIED) NUMBER OF HEAT PIPES =    84

 TEMPERATURE SUMMARY,DEGREE KELVIN
      MAXIMUM FUEL DELTA T = 110.8
      AVG DELTA T ACCROSS HEAT PIPE WALL =    6.5
      AVERAGE FUEL TEMPERATURE =1643.5
      MAXIMUM FUEL TEMPERATURE =1720.7
 BURN FRACTION OF U235 =0.0147
 FISSION DENSITY (FISSIONS/CM**3) = 1.595E+20
 FUEL SWELLING,VOLUME % = 0.

 REACTOR DIMENSIONS, METERS              FUEL ELEMENT DIMENSIONS, MM
   0.3214   CORE DIAMETER                     33.19  WIDTH ACCROSS HEX FLATS
   0.3214   CORE HEIGHT                       34.85  EQUIV. FUEL ELEMENT DIA
   0.5514   REACTOR DIAMETER                  34.85  EQUIV. FUEL REGION O.D.
   0.5314   REACTOR HEIGHT                  , 10.06  HEAT PIPE O.D.
   0.1000   REFLECTOR THICKNESS                7.79  VAPOR DIAMETER
   1.0000   PIPE LENGTH OUTSIDE REACTOR       47.66  VAPOR AREA, MM**2
   1.4264   TOTAL HEAT PIPE LENGTH
   1.5314   OVERALL REACTOR+HEAT PIPE LENGTH

 REACTOR WEIGHTS, KILOGRAMS
                 225.6   FUEL,  U235 MASS =  114.4
                 251.9   REFLECTOR
                  38.8   HEAT PIPES, WT/UNIT LENGTH (KG/M) =  27.22
                  33.0   CONTROL SYSTEM (ASSUME CONSTANT = 33 KG)
                  38.5   SUPPORT STRUCTURE (7% OF REACTOR WT)
              ---------
                 587.9   TOTAL REACTOR + HEAT PIPES

  16.94 MW/M**3,AVG POWR IN FUELSPACE    4.76 KW,POWER PER HEAT PIPE
  99.92 MW/M**2,HTPIPE AXIAL HT FLUX    0.605 MW/M**2,HTPIPE RAD HTFLX
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        TYPE GO OR STOP
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GO
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 PROB NO. 11   5-18-78    TYPE NEW INPUT: PR=1. KHP=2 ...STOP
PR=0.7 STOP

 0.700 (PR) REACTOR POWER,MW          (KCORE) (1,2/UC,UO2) CORE   =MO60UO2
 1600. (THP) HEAT PIPE TEMP,DEG K     (KREF) (1,2/BE,BEO)  REFLECTOR =BEO
 3650. (TIME) LIFETIME,DAYS           (KHP)(1,2,3/NB,MO,W) HEAT PIPE =MO
  1.00 (SLD) CORE L/D RATIO           (KVAPOR) (1,2/LI,NA) VAPOR     =LI
  10.0 (MAXL) AXIAL HT FLUX,KW/CM2 (IOPTN) (1,2)          OPTION    =2
  200. (DTFMAX) MAX FUEL DELTA T,DEG K
  1.00 (HPL1) PIPE EXTENSION,M
 NOTE, OPTIONS ARE : 1-CODE PT DESIGN, 2-SPECIFIED DESIGN
  TYPE IN ANY OF FOLLOWING : DCORE(M) XREF(M) VNFT FBETA NPIPE ..STOP
NPIPE=120 STOP
           120   (NPIPE) NO. OF HEAT PIPES
      BETA    VC     VCD    ALFA    PKAVG   BMIN    DXMIN CORGAP ENDGAP
     0.100  0.012  0.     0.600  1.500  0.050  0.080  0.015  0.005
  TYPE: STOP, OR NEW CONSTANTS IE. VC=0. PKAVG=2. ETC ...STOP
VC=0.008 STOP
 SLD INDEX =     3
 VNF = 0.100 0.200 0.300 0.400 0.500 0.600 0.700 0.800 0.900 1.000
  DC = 0.299 0.326 0.363 0.412 0.475 0.562 0.694 0.961 1.754 *.
 DCH = 0.     0.380 0.263 0.214 0.184 0.165 0.150 0.139 0.130 0.122
* * * * * * * * * * * * * TYPE GO OR START OVER * * * * * * * * * * * * *
GO
 BETA =0.1000   VNF =0.2264   VF =0.7736   DX =0.1000   DC =0.3348
 REACTIVITY CHANGES, DELTA K
      BURN = 0.01435 EXP = 0.01456 SAFE = 0.02000 TOTAL = 0.04891
 FUEL ELEMENT VOLUME FRACTIONS
     CLADDING    FUEL REGION    HEAT PIPE    WALL+WICK    VAPOR
      0.          0.8665        0.1335       0.0534       0.0801
 HEXAGONAL CORNER CORRECTION FACTOR =1.0180
 NUMBER OF HEAT PIPES =     61.1476
   MINIMUM PRACTICAL (OR SPECIFIED) NUMBER OF HEAT PIPES =  120

 TEMPERATURE SUMMARY,DEGREE KELVIN
      MAXIMUM FUEL DELTA T = 101.9
      AVG DELTA T ACCROSS HEAT PIPE WALL =    7.7
      AVERAGE FUEL TEMPERATURE =1641.7
      MAXIMUM FUEL TEMPERATURE =1713.4
 BURN FRACTION OF U235 =0.0239
 FISSION DENSITY (FISSIONS/CM**3) = 2.584E+20
 FUEL SWELLING,VOLUME % = 0.

 REACTOR DIMENSIONS, METERS            FUEL ELEMENT DIMENSIONS, MM
   0.3348   CORE DIAMETER                      29.00  WIDTH ACCROSS HEX FLATS
   0.3348   CORE HEIGHT                        30.44  EQUIV. FUEL ELEMENT DIA
   0.5648   REACTOR DIAMETER                   30.44  EQUIV. FUEL REGION O.D.
   0.5448   REACTOR HEIGHT                     11.12  HEAT PIPE O.D.
   0.1000   REFLECTOR THICKNESS                 8.62  VAPOR DIAMETER
   1.0000   PIPE LENGTH OUTSIDE REACTOR        58.31  VAPOR AREA, MM**2
   1.4398   TOTAL HEAT PIPE LENGTH
   1.5448   OVERALL REACTOR+HEAT PIPE LENGTH

 REACTOR WEIGHTS, KILOGRAMS
            242.3   FUEL,  U235 MASS =  122.8
            268.5   REFLECTOR
             68.5   HEAT PIPES, WT/UNIT LENGTH (KG/M) =  47.58
             33.0   CONTROL SYSTEM (ASSUME CONSTANT = 33 KG)
             42.9   SUPPORT STRUCTURE (7% OF REACTOR WT)
          ---------
            655.2   TOTAL REACTOR + HEAT PIPES

  27.62 MW/M**3,AVG POWR IN FUELSPACE    5.83 KW,POWER PER HEAT PIPE
 100.05 MW/M**2,HTPIPE AXIAL HT FLUX    0.644 MW/M**2,HTPIPE RAD HTFLX
                              ********************
        TYPE GO OR STOP
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GO
                              ********************
 PROB NO. 12    5-18-78     TYPE NEW INPUT: PR=1, KHP=2 ...STOP
PR=1. STOP

 1.000 (PR) REACTOR POWER,MW          (KCORE) (1,2/UC,UO2) CORE   =MO60UO2
 1600. (THP) HEAT PIPE TEMP,DEG K     (KREF)  (1,2/BE,BEO)  REFLECTOR =BEO
 3650. (TIME) LIFETIME,DAYS           (KHP)(1,2,3/NB,MO,W)  HEAT PIPE =MO
  1.00 (SLD) CORE L/D RATIO           (KVAPOR) (1,2/LI,NA)  VAPOR     =LI
  10.0 (PAXL) AXIAL HT FLUX,KW/CM2    (IOPTN) (1,2)         OPTION    =2
  200. (DTFMAX) MAX FUEL DELTA T,DEG K
  1.00 (HPL1) PIPE EXTENSION,M
 NOTE, OPTIONS ARE : 1-CODE PT DESIGN, 2-SPECIFIED DESIGN
  TYPE IN ANY OF FOLLOWING : DCORE(M) XREF(M) VNFT FBETA NPIPE ..STOP
NPIPE=162 STOP
               162  (NPIPE) NO. OF HEAT PIPES
       BETA     VC      VCD     ALFA    PKAVG   BMIN    DXMIN  CORGAP ENDGAP
     0.100   0.008   0.       0.600   1.500   0.050   0.080   0.015   0.005
  TYPE: STOP, OR NEW CONSTANTS IE. VC=0. PKAVG=2. ETC ...STOP
VC=0.006 STOP
 SLD INDEX =      3
 VNF = 0.100 0.200 0.300 0.400 0.500 0.600 0.700 0.800 0.900 1.000
  DC = 0.299 0.326 0.363 0.412 0.475 0.562 0.694 0.961 1.754 *.
 DCH = 0.     0.449 0.313 0.255 0.220 0.197 0.179 0.166 0.155 0.146
* * * * * * * * * * * * * TYPE GO OR START OVER * * * * * * * * * * * * * *
GO
 BETA =0.1000    VNF =0.2630    VF =0.7370    DX =0.1000    DC =0.3482
 REACTIVITY CHANGES, DELTA K
      BURN = 0.01915 EXP = 0.01456 SAFE = 0.02000 TOTAL = 0.05371
 FUEL ELEMENT VOLUME FRACTIONS
     CLADDING     FUEL REGION     HEAT PIPE     WALL+WICK     VAPOR
      0.           0.8238          0.1762        0.0705        0.1057
 HEXAGONAL CORNER CORRECTION FACTOR =1.0315
 NUMBER OF HEAT PIPES =    71.2219
   MINIMUM PRACTICAL (OR SPECIFIED) NUMBER OF HEAT PIPES =  162

 TEMPERATURE SUMMARY,DEGREE KELVIN
      MAXIMUM FUEL DELTA T =  87.9
      AVG DELTA T ACCROSS HEAT PIPE WALL =    7.8
      AVERAGE FUEL TEMPERATURE =1637.1
      MAXIMUM FUEL TEMPERATURE =1699.7
 BURN FRACTION OF U235 =0.0319
 FISSION DENSITY (FISSIONS/CM**3) = 3.447E+20
 FUEL SWELLING,VOLUME % = 0.

 REACTOR DIMENSIONS, METERS             FUEL ELEMENT DIMENSIONS, MM
   0.3482   CORE DIAMETER                    25.97  WIDTH ACCROSS HEX FLATS
   0.3482   CORE HEIGHT                      27.27  EQUIV. FUEL ELEMENT DIA
   0.5782   REACTOR DIAMETER                 27.27  EQUIV. FUEL REGION O.D.
   0.5582   REACTOR HEIGHT                   11.45  HEAT PIPE O.D.
   0.1000   REFLECTOR THICKNESS               8.87  VAPOR DIAMETER
   1.0000   PIPE LENGTH OUTSIDE REACTOR      61.74  VAPOR AREA, MM**2
   1.4532   TOTAL HEAT PIPE LENGTH
   1.5582   OVERALL REACTOR+HEAT PIPE LENGTH

 REACTOR WEIGHTS, KILOGRAMS
              259.4   FUEL,  U235 MASS =  131.5
              285.5   REFLECTOR
               98.8   HEAT PIPES, WT/UNIT LENGTH (KG/M) =  68.02
               33.0   CONTROL SYSTEM (ASSUME CONSTANT = 33 KG)
               47.4   SUPPORT STRUCTURE (7% OF REACTOR WT)
           ---------
              724.1   TOTAL REACTOR + HEAT PIPES

  36.84 MW/M**3,AVG POWR IN FUELSPACE   6.17 KW,POWER PER HEAT PIPE
  99.98 MW/M**2,HTPIPE AXIAL HT FLUX    0.637 MW/M**2,HTPIPE RAD HTFLX
                              ********************
       TYPE GO OR STOP
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PROB NO.  2   8-2-78      TYPE NEW INPUT: PR=1, KHP=2 ...,STOP
STOP

 1.650  (PR) REACTOR POWER,MW          (KCORE) (1,2/UC,UO2) CORE     =MO60UO2
 1600.  (THP) HEAT PIPE TEMP,DEG K     (KREF) (1,2/BE,BEO)  REFLECTOR =BEO
 3650.  (TIME) LIFETIME,DAYS           (KHP)(1,2,3/NB,MO,W) HEAT PIPE =MO
  1.00  (SLD) CORE L/D RATIO           (KVAPOR) (1,2/LI,NA) VAPOR     =LI
  10.0  (QAXL) AXIAL HT FLUX,KW/CM2    (IOPTN) (1,2)        OPTION    =2
  200.  (DTFMAX) MAX FUEL DELTA T,DEG K
  1.00  (HPL1) PIPE EXTENSION,M
 NOTE, OPTIONS ARE : 1-CODE PT DESIGN, 2-SPECIFIED DESIGN
  TYPE IN ANY OF FOLLOWING : DCORE(M) XREF(M) VNFT FBETA NPIPE ..STOP
NPIPE=162 STOP
                 162   (NPIPE) NO. OF HEAT PIPES
        BETA    VC      VCD    ALFA    PKAVG   BMIN    DXMIN  CORGAP ENDGAP
      0.100  0.      0.050  0.600  1.500  0.050  0.080  0.015  0.005
  TYPE: STOP, OR NEW CONSTANTS IE. VC=0. PKAVG=2. ETC ...STOP
BETA=0.1 VC=0.006 VCD=0. STOP
 SLD INDEX =      3
 VNF = 0.100 0.200 0.300 0.400 0.500 0.600 0.700 0.800 0.900 1.000
  DC = 0.299 0.326 0.363 0.412 0.475 0.562 0.694 0.961 1.754 *.
 DCH = 0.     ).577 0.402 0.327 0.283 0.252 0.230 0.213 0.199 0.188
* * * * * * * * * * * * TYPE GO OR RESTART * * * * * * * * * * * *
GO...PT DESIGN FOR PRES LAYTON AND HARPER
 BETA =0.1000    VNF =0.3286    VF =0.6714    DX =0.1000    DC =0.3759
 REACTIVITY CHANGES, DELTA K
      BURN = 0.02756 EXP = 0.01456 SAFE = 0.02000 TOTAL = 0.06212
 FUEL ELEMENT VOLUME FRACTIONS
     CLADDING    FUEL REGION    HEAT PIPE    WALL+WICK    VAPOR
      0.           0.7505        0.2495       0.0998       0.1497
 HEXAGONAL CORNER CORRECTION FACTOR =1.0642
 NUMBER OF HEAT PIPES =     86.1780
   MINIMUM PRACTICAL (OR SPECIFIED) NUMBER OF HEAT PIPES =  162

 TEMPERATURE SUMMARY,DEGREE KELVIN
      MAXIMUM FUEL DELTA T = 106.4
      AVG DELTA T ACCROSS HEAT PIPE WALL =  12.0
      AVERAGE FUEL TEMPERATURE =1647.4
      MAXIMUM FUEL TEMPERATURE =1724.3
 BURN FRACTION OF U235 =0.0459
 FISSION DENSITY (FISSIONS/CM**3) = 4.960E+20
 FUEL SWELLING,VOLUME % = 0.43 x3 = 1.29

 REACTOR DIMENSIONS, METERS            FUEL ELEMENT DIMENSIONS, MM
   0.3759  CORE DIAMETER                     28.04  WIDTH ACCROSS HEX FLATS
   0.3759  CORE HEIGHT                       29.44  EQUIV. FUEL ELEMENT DIA
   0.6059  REACTOR DIAMETER                  29.44  EQUIV. FUEL REGION O.D.
   0.5859  REACTOR HEIGHT                    14.71  HEAT PIPE O.D.
   0.1000  REFLECTOR THICKNESS               11.39  VAPOR DIAMETER
   1.0000  PIPE LENGTH OUTSIDE REACTOR      101.90  VAPOR AREA, MM**2
   1.4809  TOTAL HEAT PIPE LENGTH
   1.5859  OVERALL REACTOR+HEAT PIPE LENGTH

 REACTOR WEIGHTS, KILOGRAMS
             297.3  FUEL,  U235 MASS =  150.8
             322.4  REFLECTOR
             166.2  HEAT PIPES, WT/UNIT LENGTH (KG/M) = 112.25
              33.0  CONTROL SYSTEM (ASSUME CONSTANT = 33 KG)
              57.3  SUPPORT STRUCTURE (7% OF REACTOR WT)
         ---------
             876.3  TOTAL REACTOR + HEAT PIPES

  53.04 MW/M**3,AVG POWR IN FUELSPACE  10.19 KW,POWER PER HEAT PIPE
  99.96 MW/M**2,HTPIPE AXIAL HT FLUX    0.757 MW/M**2,HTPIPE RAD HTFLX
                          *********************
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     TYPE GO OR END
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```
PHOS NO.  3   8-2-78      TYPE NEW INPUT: PR=1. KHP=2 ...STOP
STOP

 1.650 (PR) REACTOR POWER,MW        (KCORE) (1,2/UC,UO2) CORE   =MO60UO2
 1600. (THP) HEAT PIPE TEMP,DEG K   (KREF) (1,2/BE,BEO)  REFLECTOR =BEO
 3650. (TIME) LIFETIME,DAYS         (KHP)(1,2,3/NB,MO,W) HEAT PIPE =MO
  1.00 (SLD) CORE L/D RATIO         (KVAPOR) (1,2/LI,NA) VAPOR     =LI
  10.0 (QAXL) AXIAL HT FLUX,KW/CM2  (IOPTN) (1,2)        OPTION    =2
  200. (DTFMAX) MAX FUEL DELTA T,DEG K
  1.00 (HPL1) PIPE EXTENSION,M
 NOTE, OPTIONS ARE : 1-CODE PT DESIGN, 2-SPECIFIED DESIGN
  TYPE IN ANY OF FOLLOWING : DCORE(M) XREF(M) VNFT FBETA NPIPE ..STOP
NPIPE=210.\.\ STOP
                 210   (NPIPE) NO. OF HEAT PIPES
        BETA    VC      VCD     ALFA    PKAVG   BMIN    DXMIN  CORGAP ENDGAP
     0.100  0.006  0.      0.600  1.500  0.050  0.080  0.015  0.005
  TYPE: STOP, OR NEW CONSTANTS IE. VC=0. PKAVG=2. ETC ...STOP
VC=0.005 STOP
 SLD INDEX =     3
 VNF = 0.100 0.200 0.300 0.400 0.500 0.600 0.700 0.800 0.900 1.000
  DC = 0.299 0.326 0.363 0.412 0.475 0.562 0.694 0.961 1.754 *.
 DCH = 0.     0.574 0.401 0.327 0.282 0.252 0.230 0.213 0.199 0.188
* * * * * * * * * * * * * * TYPE GO OR RESTART * * * * * * * * * * * * * *
GO...PT DESIGN FOR PRES LAYTON AND HARPER,NPIPE=210
 BETA =0.1000    VNF =0.3280    VF =0.6720    DX =0.1000    DC =0.3756
 REACTIVITY CHANGES, DELTA K
      BURN = 0.02760 EXP = 0.01456 SAFE = 0.02000 TOTAL = 0.06216
 FUEL ELEMENT VOLUME FRACTIONS
     CLADDING    FUEL REGION    HEAT PIPE    WALL+WICK    VAPOR
      0.           0.7504        0.2496       0.0998       0.1497
 HEXAGONAL CORNER CORRECTION FACTOR =1.0643
 NUMBER OF HEAT PIPES =    86.2171
   MINIMUM PRACTICAL (OR SPECIFIED) NUMBER OF HEAT PIPES =  210

 TEMPERATURE SUMMARY,DEGREE KELVIN
      MAXIMUM FUEL DELTA T =  82.1
      AVG DELTA T ACCROSS HEAT PIPE WALL =    9.2
      AVERAGE FUEL TEMPERATURE =1636.6
      MAXIMUM FUEL TEMPERATURE =1696.0
 BURN FRACTION OF U235 =0.0460
 FISSION DENSITY (FISSIONS/CM**3) = 4.968E+20
 FUEL SWELLING,VOLUME % = 0.37 x 3 = 1.1

 REACTOR DIMENSIONS, METERS              FUEL ELEMENT DIMENSIONS, MM
   0.3756  CORE DIAMETER                      24.62  WIDTH ACCROSS HEX FLATS
   0.3756  CORE HEIGHT                        25.85  EQUIV. FUEL ELEMENT DIA
   0.6056  REACTOR DIAMETER                   25.85  EQUIV. FUEL REGION O.D.
   0.5856  REACTOR HEIGHT                     12.92  HEAT PIPE O.D.
   0.1000  REFLECTOR THICKNESS                10.00  VAPOR DIAMETER
   1.0000  PIPE LENGTH OUTSIDE REACTOR        78.60  VAPOR AREA, MM**2
   1.4806  TOTAL HEAT PIPE LENGTH
   1.5856  OVERALL REACTOR+HEAT PIPE LENGTH

 REACTOR WEIGHTS, KILOGRAMS
                 297.0  FUEL,  U235 MASS =  150.6
                 322.1  REFLECTOR
                 166.2  HEAT PIPES, WT/UNIT LENGTH (KG/M) = 112.24
                  33.0  CONTROL SYSTEM (ASSUME CONSTANT = 33 KG)
                  57.3  SUPPORT STRUCTURE (7% OF REACTOR WT)
             ---------
                 875.5  TOTAL REACTOR + HEAT PIPES

  53.11 MW/M**3,AVG POWR IN FUELSPACE   7.86 KW,POWER PER HEAT PIPE
  99.96 MW/M**2,HTPIPE AXIAL HT FLUX    0.666 MW/M**2,HTPIPE RAD HTFLX
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TYPE GO OR END
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GO

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PROB NO. 13    5-18-78     TYPE NEW INPUT: PR=1, KHP=2 ...STOP
PR=2. STOP

 2.000  (PR) REACTOR POWER,MW          (KCORE)  (1,2/UC,UO2)  CORE    =MO60UO2
 1600.  (THP) HEAT PIPE TEMP,DEG K     (KREF)  (1,2/BE,BEO)   REFLECTOR =BEO
 3650.  (TIME) LIFETIME,DAYS           (KHP)(1,2,3/NB,MO,W)  HEAT PIPE =MO
  1.00  (FLD) CORE L/D RATIO           (KVAPOR)  (1,2/LI,NA)  VAPOR      =LI
  10.0  (MAXL) AXIAL HT FLUX,KW/CM2    (IOPTN)  (1,2)         OPTION     =2
  200.  (DTFMAX) MAX FUEL DELTA T,DEG K
  1.00  (HPL1) PIPE EXTENSION,M
 NOTE: OPTIONS ARE : 1-CODE FT DESIGN, 2-SPECIFIED DESIGN
  TYPE IN ANY OF FOLLOWING : DCORE(M) XREF(M) VNFT FBETA NPIPE ..STOP
NPIPE=210 STOP
               210  (NPIPE) NO. OF HEAT PIPES
         BETA    VC      VCD     ALFA    PKAVG   BMIN    DXMIN  CORGAP ENDGAP
        0.100   0.006   0.      0.600   1.500   0.050   0.080   0.015   0.005
  TYPE: STOP, OR NEW CONSTANTS IE. VC=0. PKAVG=2. ETC ...STOP
VC=0.005 STOP
 SLD INDEX =      3
 VNF = 0.100 0.200 0.300 0.400 0.500 0.600 0.700 0.800 0.900 1.000
  DC = 0.299 0.326 0.363 0.412 0.475 0.562 0.694 0.961 1.754 *.
 DCH = 0.     0.632 0.442 0.360 0.311 0.278 0.253 0.234 0.219 0.207
◆ ◆ ◆ ◆ ◆ ◆ ◆ ◆ ◆ ◆ ◆ ◆ ◆ ◆ TYPE GO OR START OVER ◆ ◆ ◆ ◆ ◆ ◆ ◆ ◆ ◆ ◆ ◆ ◆ ◆ ◆
GO
 BETA =0.1000    VNF =0.3566    VF =0.6434    DX =0.1000    DC =0.3893
 REACTIVITY CHANGES, DELTA K
      BURN = 0.03138 EXP = 0.01456 SAFE = 0.02000 TOTAL = 0.06594
 FUEL ELEMENT VOLUME FRACTIONS
     CLADDING    FUEL REGION    HEAT PIPE    WALL+WICK    VAPOR
      0.           0.7185        0.2815       0.1126       0.1689
 HEXAGONAL CORNER CORRECTION FACTOR =1.0825
 NUMBER OF HEAT PIPES =    92.2399
   MINIMUM PRACTICAL (OR SPECIFIED) NUMBER OF HEAT PIPES =  210

 TEMPERATURE SUMMARY,DEGREE KELVIN
      MAXIMUM FUEL DELTA T =  87.8
      AVG DELTA T ACCROSS HEAT PIPE WALL =  10.8
      AVERAGE FUEL TEMPERATURE =1640.1
      MAXIMUM FUEL TEMPERATURE =1704.0
 BURN FRACTION OF U235 =0.0523
 FISSION DENSITY (FISSIONS/CM**3) = 5.648E+20
 FUEL SWELLING,VOLUME % = 0.

 REACTOR DIMENSIONS, METERS              FUEL ELEMENT DIMENSIONS, MM
   0.3893  CORE DIAMETER                       25.52  WIDTH ACCROSS HEX FLATS
   0.3893  CORE HEIGHT                         26.80  EQUIV. FUEL ELEMENT DIA
   0.6193  REACTOR DIAMETER                    26.80  EQUIV. FUEL REGION O.D.
   0.5993  REACTOR HEIGHT                      14.22  HEAT PIPE O.D.
   0.1000  REFLECTOR THICKNESS                 11.01  VAPOR DIAMETER
   1.0000  PIPE LENGTH OUTSIDE REACTOR         95.26  VAPOR AREA, MM**2
   1.4943  TOTAL HEAT PIPE LENGTH
   1.5993  OVERALL REACTOR+HEAT PIPE LENGTH

 REACTOR WEIGHTS, KILOGRAMS
               316.6  FUEL,  U235 MASS =  160.5
               341.3  REFLECTOR
               203.3  HEAT PIPES, WT/UNIT LENGTH (KG/M) = 136.03
                33.0  CONTROL SYSTEM (ASSUME CONSTANT = 33 KG)
                62.6  SUPPORT STRUCTURE (7% OF REACTOR WT)
           ---------
               956.7  TOTAL REACTOR + HEAT PIPES

  60.37 MW/M**3,AVG POWR IN FUELSPACE    9.52 KW,POWER PER HEAT PIPE
  99.99 MW/M**2,HTPIPE AXIAL HT FLUX   0.707 MW/M**2,HTPIPE RAD HTFLX
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TYPE GO OR STOP

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PROB NO. 14    5-18-78     TYPE NEW INPUT: PR=1, KHP=2 ...STOP
PR=4, STOP

 4.000 (PR) REACTOR POWER,MW         (KCORE) (1,2/UC,UO2) CORE  =MO60UO2
 1600. (THP) HEAT PIPE TEMP,DEG K    (KREF) (1,2/BE,BEO)  REFLECTOR =BEO
 3650. (TIME) LIFETIME,DAYS          (KHP) (1,2,3/NB,MO,W) HEAT PIPE =MO
  1.00 (SLD) CORE L/D RATIO          (KVAPOR) (1,2/LI,NA)  VAPOR     =LI
  10.0 (QAXL) AXIAL HT FLUX,KW/CM2 (IOPTN) (1,2)           OPTION    =2
  200. (DTFMAX) MAX FUEL DELTA T,DEG K
  1.00 (HPL1) PIPE EXTENSION,M
 NOTE, OPTIONS ARE : 1-CODE PT DESIGN, 2-SPECIFIED DESIGN
  TYPE IN ANY OF FOLLOWING : DCORE(M) XREF(M) VNFT BETA NPIPE ..STOP
NPIPE=266 STOP
             266  (NPIPE) NO. OF HEAT PIPES
        BETA    VC      VCD    ALFA   PKAVG   BMIN   DXMIN  CORGAP ENDGAP
       0.100  0.005  0.      0.600  1.500  0.050  0.080  0.015  0.005
  TYPE: STOP, OR NEW CONSTANTS IE. VC=0. PKAVG=2. ETC ...STOP
VC=0.004 STOP
 SLD INDEX =    3
 VNF = 0.100 0.200 0.300 0.400 0.500 0.600 0.700 0.800 0.900 1.000
  DC = 0.299 0.326 0.363 0.412 0.475 0.562 0.694 0.961 1.754 *.
 DCH = 0.    0.890 0.624 0.508 0.439 0.392 0.358 0.331 0.310 0.292
* * * * * * * * * * * * * * * TYPE GO OR START OVER * * * * * * * * * * * * * *
GO
 BETA =0.1000    VNF =0.4720    VF =0.5280    DX =0.1000    DC =0.4554
 REACTIVITY CHANGES, DELTA K
      BURN = 0.04777 EXP = 0.01456 SAFE = 0.02000 TOTAL = 0.08233
 FUEL ELEMENT VOLUME FRACTIONS
     CLADDING    FUEL REGION    HEAT PIPE    WALL+WICK    VAPOR
      0.           0.5890        0.4110       0.1644       0.2466
 HEXAGONAL CORNER CORRECTION FACTOR =1.1840
 NUMBER OF HEAT PIPES =  115.0234
   MINIMUM PRACTICAL (OR SPECIFIED) NUMBER OF HEAT PIPES =  266

 TEMPERATURE SUMMARY,DEGREE KELVIN
      MAXIMUM FUEL DELTA T =  86.5
      AVG DELTA T ACCROSS HEAT PIPE WALL =  14.6
      AVERAGE FUEL TEMPERATURE =1643.4
      MAXIMUM FUEL TEMPERATURE =1708.3
 BURN FRACTION OF U235 =0.0796
 FISSION DENSITY (FISSIONS/CM**3) = 8.598E+20
 FUEL SWELLING,VOLUME % = 0.

 REACTOR DIMENSIONS, METERS                FUEL ELEMENT DIMENSIONS, MM
   0.4554  CORE DIAMETER                      26.54  WIITH ACCROSS HEX FLATS
   0.4554  CORE HEIGHT                        27.87  EQUIV. FUEL ELEMENT DIA
   0.6554  REACTOR DIAMETER                   27.87  EQUIV. FUEL REGION O.D.
   0.6654  REACTOR HEIGHT                     17.87  HEAT PIPE O.D.
   0.1000  REFLECTOR THICKNESS                13.84  VAPOR DIAMETER
   1.0000  PIPE LENGTH OUTSIDE REACTOR 150.41  VAPOR AREA, MM**2
   1.5604  TOTAL HEAT PIPE LENGTH
   1.6654  OVERALL REACTOR+HEAT PIPE LENGTH

 REACTOR WEIGHTS, KILOGRAMS
               416.0  FUEL,  U235 MASS =  210.9
               442.0  REFLECTOR
               424.5  HEAT PIPES, WT/UNIT LENGTH (KG/M) = 272.05
                33.0  CONTROL SYSTEM (ASSUME CONSTANT = 33 KG)
                92.1  SUPPORT STRUCTURE (7% OF REACTOR WT)
            ---------
              1407.5  TOTAL REACTOR + HEAT PIPES

  91.91 MW/M**3,AVG POWR IN FUELSPACE  15.04 KW,POWER PER HEAT PIPE
  99.93 MW/M**2,HTPIPE AXIAL HT FLUX   0.760 MW/M**2,HTPIPE RAD HTFLX
                              *********************

     TYPE GO OR STOP
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PROJ NO. 15   5-18-78     TYPE NEW INPUT! PR=1. KHP=2 ...STOP
PR=0.2 THP=1750. STOP

 0.200 (PR) REACTOR POWER,MW              (KCORE) (1,2/UC,UO2) CORE    =MO60UO2
 1750. (THP) HEAT PIPE TEMP,DEG K         (KREF)  (1,2/BE,BEO)  REFLECTOR =BEO
 3650. (TIME) LIFETIME,DAYS               (KHP)(1,2,3/NB,MO,W)  HEAT PIPE =MO
  1.00 (ZLD) CORE L/D RATIO               (KVAPOR) (1,2/LI,NA)  VAPOR     =LI
  10.0 (QAXL) AXIAL HT FLUX,KW/CM2        (IOPTN)  (1,2)        OPTION    =2
  200. (DTFMAX) MAX FUEL DELTA T,DEG K
  1.00 (HPL1) PIPE EXTENSION,M
 NOTE, OPTIONS ARE ! 1-CODE PT DESIGN, 2-SPECIFIED DESIGN
  TYPE IN ANY OF FOLLOWING ! DCORE(M) XREF(M) VNFT FBETA NPIPE ..STOP
NPIPE=84 STOP
              84   (NPIPE) NO. OF HEAT PIPES
        BETA    VC      VCD     ALFA    PKAVG   BMIN    DXMIN  CORGAP  ENDGAP
       0.100  0.004  0.        0.600  1.500  0.050  0.000  0.015  0.005
  TYPE! STOP, OR NEW CONSTANTS IE. VC=0. PKAVG=2. ETC ...STOP
VC=0.012 STOP
 ZLD INDEX =      3
 VNF = 0.100 0.200 0.300 0.400 0.500 0.600 0.700 0.800 0.900 1.000
  DC = 0.299 0.326 0.363 0.412 0.475 0.562 0.694 0.961 1.754 *.
 DCH = 0.    0.207 0.142 0.115 0.099 0.088 0.081 0.074 0.070 0.066
* * * * * * * * * * * * * TYPE GO OR START OVER * * * * * * * * * * * * *
GO
 BETA =0.1000   VNF =0.1501   VF =0.8499   DX =0.1000   DC =0.3115
 REACTIVITY CHANGES, DELTA K
     BURN = 0.00464 EXP = 0.01612 SAFE = 0.02000 TOTAL = 0.04076
 FUEL ELEMENT VOLUME FRACTIONS
     CLADDING    FUEL REGION    HEAT PIPE    WALL+WICK    VAPOR
     0.           0.9558         0.0442       0.0177       0.0265
 HEXAGONAL CORNER CORRECTION FACTOR =1.0020
 NUMBER OF HEAT PIPES =    31.5836
   MINIMUM PRACTICAL (OR SPECIFIED) NUMBER OF HEAT PIPES =    84

 TEMPERATURE SUMMARY,DEGREE KELVIN
      MAXIMUM FUEL DELTA T =  75.2
      AVG DELTA T ACCROSS HEAT PIPE WALL =    3.4
      AVERAGE FUEL TEMPERATURE =1778.4
      MAXIMUM FUEL TEMPERATURE =1830.3
 BURN FRACTION OF U235 =0.0077
 FISSION DENSITY (FISSIONS/CM**3) = 8.345E+19
 FUEL SWELLING,VOLUME % = 1.4

 REACTOR DIMENSIONS, METERS                FUEL ELEMENT DIMENSIONS, MM
   0.3115   CORE DIAMETER                     32.18   WIDTH ACCROSS HEX FLATS
   0.3115   CORE HEIGHT                       33.79   EQUIV. FUEL ELEMENT DIA
   0.5415   REACTOR DIAMETER                  33.79   EQUIV. FUEL REGION O.D.
   0.5215   REACTOR HEIGHT                     7.11   HEAT PIPE O.D.
   0.1000   REFLECTOR THICKNESS                5.51   VAPOR DIAMETER
   1.0000   PIPE LENGTH OUTSIDE REACTOR       23.80   VAPOR AREA, MM**2
   1.4165   TOTAL HEAT PIPE LENGTH
   1.5215   OVERALL REACTOR+HEAT PIPE LENGTH

 REACTOR WEIGHTS, KILOGRAMS
              214.3   FUEL,   U235 MASS =   108.7
              240.2   REFLECTOR
               19.3   HEAT PIPES, WT/UNIT LENGTH (KG/M) =  13.60
               33.0   CONTROL SYSTEM (ASSUME CONSTANT = 33 KG)
               35.5   SUPPORT STRUCTURE (7% OF REACTOR WT)
          ----------
              542.2   TOTAL REACTOR + HEAT PIPES

   8.92 MW/M**3,AVG POWR IN FUELSPACE     2.38 KW,POWER PER HEAT PIPE
 100.04 MW/M**2,HTPIPE AXIAL HT FLUX     0.442 MW/M**2,HTPIPE RAD HTFLX
                  *********************
      TYPE GO OR STOP
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GO
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 PROB NO. 16    5-18-78     TYPE NEW INPUT: PR=1. KHP=2 ...STOP
PR=0.4 STOP

 0.400 (PR) REACTOR POWER,MW             (KCORR) (1,2/UC,UO2) CORE  =MO60UO2
 1750. (THP) HEAT PIPE TEMP,DEG K        (KREF) (1,2/BE,BEO)  REFLECTOR =BEO
 3650. (TIME) LIFETIME,DAYS              (KHP)(1,2,3/NB,MO,W) HEAT PIPE =MO
  1.00 (SLD) CORE L/D RATIO              (KVAPOR) (1,2/LI,NA) VAPOR     =LI
  10.0 (DAXL) AXIAL HT FLUX,KW/CM2 (IOPTN) (1,2)              OPTION    =2
  200. (DTFMAX) MAX FUEL DELTA T,DEG K
  1.00 (HPL1) PIPE EXTENSION,M
NOTE, OPTIONS ARE : 1-CODE PT DESIGN, 2-SPECIFIED DESIGN
 TYPE IN ANY OF FOLLOWING : DCORE(M) XREF(M) VNFT FBETA NPIPE ..STOP
NPIPE=84 STOP
               84   (NPIPE) NO. OF HEAT PIPES
      BETA     VC      VCD     ALFA     PKAVG   SMIN    DXMIN CORGAP ENDGAP
     0.100  0.012  0.        0.600  1.500  0.050  0.080  0.015  0.005
 TYPE: STOP, OR NEW CONSTANTS IE. VC=0. PKAVG=2. ETC ...STOP
STOP
 SLD INDEX =      3
 VNF = 0.100 0.200 0.300 0.400 0.500 0.600 0.700 0.800 0.900 1.000
  DC = 0.299 0.326 0.363 0.412 0.475 0.562 0.694 0.961 1.754 *.
 DCH = 0.     0.293 0.201 0.163 0.140 0.125 0.114 0.105 0.098 0.093
* * * * * * * * * * * * TYPE GO OR START OVER * * * * * * * * * * * * * *
GO
 BETA =0.1000    VNF =0.1848    VF =0.8152    DX =0.1000    DC =0.3214
 REACTIVITY CHANGES, DELTA K
      BURN = 0.00881 EXP = 0.01612 SAFE = 0.02000 TOTAL = 0.04493
 FUEL ELEMENT VOLUME FRACTIONS
     CLADDING    FUEL REGION    HEAT PIPE    WALL+WICK    VAPOR
      0.            0.9167        0.0[illegible]       0.0333       0.0500
 HEXAGONAL CORNER CORRECTION FACTOR =1.0070
 NUMBER OF HEAT PIPES =   46.5570
   MINIMUM PRACTICAL (OR SPECIFIED) NUMBER OF HEAT PIPES =    84

 TEMPERATURE SUMMARY,DEGREE KELVIN
      MAXIMUM FUEL DELTA T = 110.8
      AVG DELTA T ACCROSS HEAT PIPE WALL =    6.5
      AVERAGE FUEL TEMPERATURE =1793.5
      MAXIMUM FUEL TEMPERATURE =1870.7
 BURN FRACTION OF U235 =0.0147
 FISSION DENSITY (FISSIONS/CM**3) = 1.585E+20
 FUEL SWELLING,VOLUME % = 2.6

 REACTOR DIMENSIONS, METERS               FUEL ELEMENT DIMENSIONS, MM
   0.3214  CORE DIAMETER                        33.19  WIDTH ACCROSS HEX FLATS
   0.3214  CORE HEIGHT                          34.85  EQUIV. FUEL ELEMENT DIA
   0.5514  REACTOR DIAMETER                     34.85  EQUIV. FUEL REGION O.D.
   0.5314  REACTOR HEIGHT                       10.06  HEAT PIPE O.D.
   0.1000  REFLECTOR THICKNESS                   7.79  VAPOR DIAMETER
   1.0000  PIPE LENGTH OUTSIDE REACTOR          47.66  VAPOR AREA, MM**2
   1.4264  TOTAL HEAT PIPE LENGTH
   1.5314  OVERALL REACTOR+HEAT PIPE LENGTH

 REACTOR WEIGHTS, KILOGRAMS
                225.6  FUEL,  U235 MASS =  114.4
                251.9  REFLECTOR
                 38.8  HEAT PIPES, WT/UNIT LENGTH (KG/M) =  27.22
                 33.0  CONTROL SYSTEM (ASSUME CONSTANT = 33 KG)
                 38.5  SUPPORT STRUCTURE (7% OF REACTOR WT)
            ---------
                587.9  TOTAL REACTOR + HEAT PIPES

  16.94 MW/M**3,AVG POWR IN FUELSPACE    4.76 KW,POWER PER HEAT PIPE
  99.92 MW/M**2,HTPIPE AXIAL HT FLUX    0.605 MW/M**2,HTPIPE RAD HTFLX
                      ********************
        TYPE GO OR STOP
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                         ********************
 PROB NO. 17   5-18-78    TYPE NEW INPUT! PR=1. KHP=2 ...STOP
PR=0.7 STOP

 0.700 (PR) REACTOR POWER,MW         (KCORE) (1,2/UC,UO2) CORE   =MO60UO2
 1750.  (THP) HEAT PIPE TEMP,DEG K   (KREF)  (1,2/BE,BEO)  REFLECTOR =BEO
 3650.  (TIME) LIFETIME,DAYS         (KHP)(1,2,3/NB,MO,W)  HEAT PIPE =MO
  1.00 (FLD) CORE L/D RATIO          (KVAPOR) (1,2/LI,NA)  VAPOR     =LI
  10.0 (PAXL) AXIAL HT FLUX,KW/CM2  (IOPTN) (1,2)          OPTION    =2
  200.  (DTFMAX) MAX FUEL DELTA T,DEG K
  1.00 (HPL1) PIPE EXTENSION,M
 NOTE, OPTIONS ARE ! 1-CODE PT DESIGN, 2-SPECIFIED DESIGN
  TYPE IN ANY OF FOLLOWING ! DCORE(M) XREF(M) VNFT FBETA NPIPE ..STOP
NPIPE=120 STOP
                120  (NPIPE) NO. OF HEAT PIPES
        BETA    VC     VCD    ALFA   PKAVG  BMIN   DXMIN CORGAP ENDGAP
      0.100  0.012  0.      0.600  1.500  0.050  0.080  0.015  0.005
  TYPE! STOP, OR NEW CONSTANTS IE. VC=0. PKAVG=2. ETC ...STOP
VC=0.008 STOP
 FLD INDEX =     3
 VNF = 0.100 0.200 0.300 0.400 0.500 0.600 0.700 0.800 0.900 1.000
  DC = 0.299 0.326 0.363 0.412 0.475 0.562 0.694 0.961 1.754 *.
 DCH = 0.    0.380 0.263 0.214 0.184 0.165 0.150 0.139 0.130 0.122
* * * * * * * * * * * * TYPE GO OR START OVER * * * * * * * * * * * *
GO
 BETA =0.1000   VNF =0.2264   VF =0.7736   DX =0.1000   DC =0.3348
 REACTIVITY CHANGES, DELTA K
     BURN = 0.01435 EXP = 0.01612 SAFE = 0.02000 TOTAL = 0.05047
 FUEL ELEMENT VOLUME FRACTIONS
     CLADDING    FUEL REGION    HEAT PIPE    WALL+WICK    VAPOR
     0.            0.8665        0.1335       0.0534       0.0801
 HEXAGONAL CORNER CORRECTION FACTOR =1.0180
 NUMBER OF HEAT PIPES =    61.1476
   MINIMUM PRACTICAL (OR SPECIFIED) NUMBER OF HEAT PIPES =  120

 TEMPERATURE SUMMARY,DEGREE KELVIN
      MAXIMUM FUEL DELTA T = 101.9
      AVG DELTA T ACCROSS HEAT PIPE WALL =    7.7
      AVERAGE FUEL TEMPERATURE =1791.7
      MAXIMUM FUEL TEMPERATURE =1863.4
 BURN FRACTION OF U235 =0.0239
 FISSION DENSITY (FISSIONS/CM**3) = 2.584E+20
 FUEL SWELLING,VOLUME % = 4.3

 REACTOR DIMENSIONS, METERS              FUEL ELEMENT DIMENSIONS, MM
   0.3348  CORE DIAMETER                    29.00  WIDTH ACCROSS HEX FLATS
   0.3348  CORE HEIGHT                      30.44  EQUIV. FUEL ELEMENT DIA
   0.5648  REACTOR DIAMETER                 30.44  EQUIV. FUEL REGION O.D.
   0.5448  REACTOR HEIGHT                   11.12  HEAT PIPE O.D.
   0.1000  REFLECTOR THICKNESS               8.62  VAPOR DIAMETER
   1.0000  PIPE LENGTH OUTSIDE REACTOR      58.31  VAPOR AREA, MM**2
   1.4398  TOTAL HEAT PIPE LENGTH
   1.5448  OVERALL REACTOR+HEAT PIPE LENGTH

 REACTOR WEIGHTS, KILOGRAMS
              242.3  FUEL,  U235 MASS =  122.8
              268.5  REFLECTOR
               68.5  HEAT PIPES, WT/UNIT LENGTH (KG/M) =  47.58
               33.0  CONTROL SYSTEM (ASSUME CONSTANT = 33 KG)
               42.9  SUPPORT STRUCTURE (7% OF REACTOR WT)
           ---------
              655.2  TOTAL REACTOR + HEAT PIPES

  27.62 MW/M**3,AVG POWR IN FUELSPACE    5.83 KW,POWER PER HEAT PIPE
 100.05 MW/M**2,HTPIPE AXIAL HT FLUX    0.644 MW/M**2,HTPIPE RAD HTFLX
                         ********************
      TYPE GO OR STOP
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 PROB NO. 18   5-18-78    TYPE NEW INPUT: PR=1. KHP=2 ...STOP
PR=1. STOP

 1.000 (PR) REACTOR POWER,MW          (KCORE) (1,2/UC,UO2) CORE   =MO60UO2
 1750. (THP) HEAT PIPE TEMP,DEG K    (KREF) (1,2/BE,BEO)  REFLECTOR =BEO
 3650. (TIME) LIFETIME,DAYS          (KHP)(1,2,3/NB,MO,W) HEAT PIPE =MO
  1.00 (RLD) CORE L/D RATIO          (KVAPOR) (1,2/LI,NA) VAPOR     =LI
  10.0 (QAXL) AXIAL HT FLUX,KW/CM2 (IOPTN) (1,2)          OPTION    =2
  200. (DTFMAX) MAX FUEL DELTA T,DEG K
  1.00 (HPL1) PIPE EXTENSION,M
 NOTE, OPTIONS ARE : 1-CODE RT DESIGN, 2-SPECIFIED DESIGN
  TYPE IN ANY OF FOLLOWING : DCORE(M) XREF(M) VNFT FBETA NPIPE ..STOP
NPIPE=162 STOP
               162  (NPIPE) NO. OF HEAT PIPES
      BETA    VC     VCD    ALFA   PKAVG  BMIN   DXMIN  CORGAP  ENDGAP
     0.100  0.008  0.      0.600  1.500  0.050  0.080  0.015  0.005
  TYPE: STOP, OR NEW CONSTAN : IE. VC=0. PKAVG=2. ETC ...STOP
VC=0.006 STOP
 SLD INDEX =     3
 VNF = 0.100 0.200 0.300 0.400 0.500 0.600 0.700 0.800 0.900 1.000
  DC = 0.299 0.326 0.363 0.412 0.475 0.562 0.694 0.961 1.754 *.
 DCH = 0.    0.449 0.313 0.255 0.220 0.197 0.179 0.166 0.155 0.146
* * * * * * * * * * * * TYPE GO OR START OVER * * * * * * * * * * * * *
GO
 BETA =0.1000   VNF =0.2630   VF =0.7370   DX =0.1000   DC =0.3482
 REACTIVITY CHANGES, DELTA K
     BURN = 0.01915 EXP = 0.01612 SAFE = 0.02000 TOTAL = 0.05527
 FUEL ELEMENT VOLUME FRACTIONS
     CLADDING    FUEL REGION    HEAT PIPE    WALL+WICK     VAPOR
    0.            0.8238         0.1762       0.0705       0.1057
 HEXAGONAL CORNER CORRECTION FACTOR =1.0315
 NUMBER OF HEAT PIPES =    71.2219
   MINIMUM PRACTICAL (OR SPECIFIED) NUMBER OF HEAT PIPES =  162

 TEMPERATURE SUMMARY,DEGREE KELVIN
      MAXIMUM FUEL DELTA T =  87.9
      AVG DELTA T ACCROSS HEAT PIPE WALL =   7.8
      AVERAGE FUEL TEMPERATURE =1787.1
      MAXIMUM FUEL TEMPERATURE =1849.7
 BURN FRACTION OF U235 =0.0319
 FISSION DENSITY (FISSIONS/CM**3) = 3.447E+20
 FUEL SWELLING,VOLUME % = ~~6~~ ~ 5.7

 REACTOR DIMENSIONS, METERS              FUEL ELEMENT DIMENSIONS, MM
   0.3482  CORE DIAMETER                     25.97  WIDTH ACCROSS HEX FLATS
   0.3482  CORE HEIGHT                       27.27  EQUIV. FUEL ELEMENT DIA
   0.5782  REACTOR DIAMETER                  27.27  EQUIV. FUEL REGION O.D.
   0.5582  REACTOR HEIGHT                    11.45  HEAT PIPE O.D.
   0.1000  REFLECTOR THICKNESS                8.87  VAPOR DIAMETER
   1.0000  PIPE LENGTH OUTSIDE REACTOR       61.74  VAPOR AREA, MM**2
   1.4532  TOTAL HEAT PIPE LENGTH
   1.5582  OVERALL REACTOR+HEAT PIPE LENGTH

 REACTOR WEIGHTS, KILOGRAMS
             259.4  FUEL,  U235 MASS =  131.5
             285.5  REFLECTOR
              98.8  HEAT PIPES, WT/UNIT LENGTH (KG/M) =  68.02
              33.0  CONTROL SYSTEM (ASSUME CONSTANT = 33 KG)
              47.4  SUPPORT STRUCTURE (7% OF REACTOR WT)
          ---------
             724.1  TOTAL REACTOR + HEAT PIPES

  36.84 MW/M**3,AVG POWR IN FUELSPACE   6.17 KW,POWER PER HEAT PIPE
  99.98 MW/M**2,HTPIPE AXIAL HT FLUX   0.637 MW/M**2,HTPIPE RAD HTFLX
                        ********************
     TYPE GO OR STOP
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v PROB NO.  1   6-21-78     TYPE NEW INPUT: PR=1. KHP=2 ...STOP
 PR=2. THP=1750. TIME=3650. KCORE=5 KREF=2 KVAPOR=1 IOPTN=2 STOP

  2.000 (PR) REACTOR POWER,MW          (KCORE) (1,2/UC,UO2) CORE  =MO60UO2
  1750. (THP) HEAT PIPE TEMP,DEG K     (KREF) (1,2/BE,BEO)  REFLECTOR =BEO
  3650. (TIME) LIFETIME,DAYS           (KHP)(1,2,3/NB,MO,W) HEAT PIPE =MO
   1.00 (ZLD) CORE L/D RATIO           (KVAPOR) (1,2/LI,NA) VAPOR     =LI
   10.0 (QAXL) AXIAL HT FLUX,KW/CM2 (IOPTN) (1,2)        OPTION    =2
   200. (DTFMAX) MAX FUEL DELTA T,DEG K
   1.00 (HPL1) PIPE EXTENSION,M
  NOTE, OPTIONS ARE : 1-CODE PT DESIGN, 2-SPECIFIED DESIGN
   TYPE IN ANY OF FOLLOWING : DCORE(M) XREF(M) VNFT FZETI NPIPE ..STOP
 NPIPE=210 STOP
                     210   (NPIPE) NO. OF HEAT PIPES
        ZETA    VC      VCD    ALFA   PKAVG  BMIN   DXMIN CORGAP ENDGAP
      0.100  0.      0.050  0.600  1.500  0.050  0.080  0.015  0.005
   TYPE: STOP, OR NEW CONSTANTS IE. VC=0. PKAVG=2. ETC ...STOP
 VC=0.005 VCD=0. STOP
  ZLD INDEX =     3
  VNF = 0.100 0.200 0.300 0.400 0.500 0.600 0.700 0.800 0.900 1.000
   DC = 0.299 0.326 0.363 0.412 0.475 0.562 0.694 0.961 1.754 *.
  DCH = 0.     0.632 0.442 0.360 0.311 0.278 0.253 0.234 0.219 0.207
 * * * * * * * * * * * * * TYPE GO OR START OVER * * * * * * * * * * * * * *
 GO...ADJUST ZETA FOR 3.33% SWELLING
  ZETA =0.1000    VNF =0.3566    VF =0.6434    DX =0.1000    DC =0.3893
  REACTIVITY CHANGES, DELTA K
      BURN = 0.03138 EXP = 0.01612 SAFE = 0.02000 TOTAL = 0.06750
  FUEL ELEMENT VOLUME FRACTIONS
     CLADDING    FUEL REGION    HEAT PIPE    WALL+WICK    VAPOR
      0.            0.7185        0.2815       0.1126       0.1689
  HEXAGONAL CORNER CORRECTION FACTOR =1.0825
  NUMBER OF HEAT PIPES =    92.2398
    MINIMUM PRACTICAL (OR SPECIFIED) NUMBER OF HEAT PIPES =  210

  TEMPERATURE SUMMARY,DEGREE KELVIN
       MAXIMUM FUEL DELTA T =  87.8
       AVG DELTA T ACCROSS HEAT PIPE WALL =  10.8
       AVERAGE FUEL TEMPERATURE =1790.1
       MAXIMUM FUEL TEMPERATURE =1854.0
  BURN FRACTION OF U235 =0.0523
  FISSION DENSITY (FISSIONS/CM**3) = 5.648E+20
  FUEL SWELLING,VOLUME % = 3.10 x3 =9.3

  REACTOR DIMENSIONS, METERS            FUEL ELEMENT DIMENSIONS, MM
    0.3893  CORE DIAMETER                    25.52  WIDTH ACCROSS HEX FLATS
    0.3893  CORE HEIGHT                      26.80  EQUIV. FUEL ELEMENT DIA
    0.6193  REACTOR DIAMETER                 26.80  EQUIV. FUEL REGION O.D.
    0.5993  REACTOR HEIGHT                   14.22  HEAT PIPE O.D.
    0.1000  REFLECTOR THICKNESS              11.01  VAPOR DIAMETER
    1.0000  PIPE LENGTH OUTSIDE REACTOR      95.26  VAPOR AREA, MM**2
    1.4943  TOTAL HEAT PIPE LENGTH
    1.5993  OVERALL REACTOR+HEAT PIPE LENGTH

  REACTOR WEIGHTS, KILOGRAMS
                 316.6   FUEL,  U235 MASS =  160.5
                 341.3   REFLECTOR
                 203.3   HEAT PIPES, WT/UNIT LENGTH (KG/M) = 136.03
                  33.0   CONTROL SYSTEM (ASSUME CONSTANT = 33 KG)
                  62.6   SUPPORT STRUCTURE (7% OF REACTOR WT)
               ---------
                 956.7   TOTAL REACTOR + HEAT PIPES

   60.37 MW/M**3,AVG POWR IN FUELSPACE    9.52 KW,POWER PER HEAT  PIPE
   99.98 MW/M**2,HTPIPE AXIAL HT FLUX    0.707 MW/M**2,HTPIPE RAD HTFLX
                                 *********************

       TYPE GO OR END
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GO
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 PROB NO.  3   6-14-78    TYPE NEW INPUT: PR=1. KHP=2 ...STOP
STOP

 4.000 (PR) REACTOR POWER,MW          (KCORE) (1,2/UC,UO2) CORE    =MO60UO2
 1750. (THP) HEAT PIPE TEMP,DEG K     (KREF) (1,2/BE,BEO)  REFLECTOR =BEO
 3650. (TIME) LIFETIME,DAYS           (KHP)(1,2,3/NB,MO,W) HEAT PIPE =MO
  1.00 (SLD) CORE L/D RATIO           (KVAPOR) (1,2/LI,NA) VAPOR     =LI
  10.0 (P4/L) AXIAL HT FLUX,KW/CM2 (IOPTN) (1,2)           OPTION    =2
  200. (DTFMAX) MAX FUEL DELTA T,DEG K
  1.00 (HPL1) PIPE EXTENSION,M
 NOTE, OPTIONS ARE : 1-CODE PT DESIGN, 2-SPECIFIED DESIGN
  TYPE IN ANY OF FOLLOWING : DCORE(M) XREF(M) VNFT FBETA NPIPE ..STOP
NPIPE=264 STOP
              264  (NPIPE) NO. OF HEAT PIPES
      BETA    VC      VCD     ALFA    PKAVG   BMIN    DXMIN  CORGAP  ENDGAP
     0.200  0.004  0.       0.600  1.500  0.050  0.080  0.015  0.005
  TYPE: STOP, OR NEW CONSTANTS IE. VC=0. PKAVG=2. ETC ...STOP
BETA=0.289 STOP
 SLD INDEX =     3
 VNF = 0.100 0.200 0.300 0.400 0.500 0.600 0.700 0.800 0.900 1.000
  DC = 0.299 0.326 0.363 0.412 0.475 0.562 0.694 0.961 1.754 *.
 DCH = 0.     0.    2.720 0.747 0.538 0.443 0.385 0.345 0.315 0.292
* * * * * * * * * * * * * * TYPE GO OR START OVER * * * * * * * * * * * * * *
GO...ADJUST BETA TO LIMIT INDICATED SWELLING TO 3.33% (IE 10% SWELL.)
 BETA =0.2890    VNF =0.5331    VF =0.4669    DX =0.1000    DC =0.5003
 REACTIVITY CHANGES, DELTA K
      BURN = 0.04075 EXP = 0.01612 SAFE = 0.02000 TOTAL = 0.07687
 FUEL ELEMENT VOLUME FRACTIONS
     CLADDING    FUEL REGION    HEAT PIPE    WALL+WICK    VAPOR
      0.            0.6594       0.3406       0.1363       0.2044
 HEXAGONAL CORNER CORRECTION FACTOR =1.1230
 NUMBER OF HEAT PIPES =   123.4099
   MINIMUM PRACTICAL (OR SPECIFIED) NUMBER OF HEAT PIPES =  264

 TEMPERATURE SUMMARY,DEGREE KELVIN
      MAXIMUM FUEL DELTA T =  93.5
      AVG DELTA T ACCROSS HEAT PIPE WALL =  13.4
      AVERAGE FUEL TEMPERATURE =1794.5
      MAXIMUM FUEL TEMPERATURE =1863.5
 BURN FRACTION OF U235 =0.0679
 FISSION DENSITY (FISSIONS/CM**3)  = 5.794E+20
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FUEL SWELLING,VOLUME % = ~~2.35~~ 10.0 %

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 REACTOR DIMENSIONS, METERS              FUEL ELEMENT DIMENSIONS, MM
   0.5003  CORE DIAMETER                  29.27  WIDTH ACCROSS HEX FLATS
   0.5003  CORE HEIGHT                    30.73  EQUIV. FUEL ELEMENT DIA
   0.7303  REACTOR DIAMETER               30.73  EQUIV. FUEL REGION O.D.
   0.7103  REACTOR HEIGHT                 17.94  HEAT PIPE O.D.
   0.1000  REFLECTOR THICKNESS            13.89  VAPOR DIAMETER
   1.0000  PIPE LENGTH OUTSIDE REACTOR  151.58  VAPOR AREA, MM**2
   1.6053  TOTAL HEAT PIPE LENGTH
   1.7103  OVERALL REACTOR+HEAT PIPE LENGTH

 REACTOR WEIGHTS, KILOGRAMS
              487.7  FUEL,  U235 MASS =  247.2
              518.0  REFLECTOR
              436.8  HEAT PIPES, WT/UNIT LENGTH (KG/M) = 272.12
               33.0  CONTROL SYSTEM (ASSUME CONSTANT = 33 KG)
              103.3  SUPPORT STRUCTURE (7% OF REACTOR WT)
           ----------
             1578.8  TOTAL REACTOR + HEAT PIPES

  61.94 MW/M**3,AVG POWR IN FUELSPACE  15.15 KW,POWER PER HEAT PIPE
  99.96 MW/M**2,HTPIPE AXIAL HT FLUX    0.694 MW/M**2,HTPIPE RAD HTFLX
                    ********************
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